LANDSCAPE CHANGE AND HUMAN-ENVIRONMENT INTERACTIONS: IMPLICATIONS FOR NATURAL RESOURCE MANAGEMENT IN URBANIZING AREAS

by

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ABSTRACT

MONICA ANN DORNING. Landscape change and human-environment interactions: implications for natural resource management in urbanizing areas. (Under the direction of DR. ROSS K. MEENTEMEYER)

Worldwide changes in land use and land cover alter the spatial distributions of natural resources and ecosystem functions. Here I examined the pattern and process of landscape change in the Charlotte, North Carolina metropolitan region, to understand how these changes originate from and have influence on human decisions regarding land management and policy formation. First, I simulated future landscape patterns that could arise from conservation-based land use policies and assessed the potential impacts to priority natural resources and landscape composition. Second, I analyzed the process of landscape change as it originates with the decisions of individual forest owners by utilizing a unique combination of individual, site, and landscape level data within a structural equation modeling framework. Third, I used a stated preference survey to examine how those individual decisions may change with new global markets for biofuels. My findings highlight the importance of considering landscape change as a multi-scale process with integrated human, environmental, and spatial components. Advancing our understanding of these processes will support planning organizations at local to regional levels in developing sustainable natural resource management plans that are in line with societal values while preserving biodiversity and ecosystem function.

DEDICATION

To my parents

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INTRODUCTION

Worldwide increases in population and consumption of natural resources are driving unprecedented changes to earth's landscapes (Foley et al. 2005, UNFPA 2007) resulting in losses of global biodiversity and the reduced resilience of ecosystems and societies (Lambin et al. 2001, Andersson 2006, McKinney 2006). Landscape change is governed by complex interactions between social and ecological systems across multiple scales (Stern 1993, Best 2002, Liu et al. 2007) – global progress toward sustainable land use will be heavily dependent upon local relationships between individuals and communities and their environments (Stern 2000, Uzzell et al. 2002, Ostrom 2009). However human-environment interactions are also changing, as land conversion alters the experiences of people within their environments (Miller 2005, Jorgensen and Stedman 2006).

The environmental impacts of land use change stem from the physical alteration of the earth's surface, including alteration of hydrology, biogeochemical cycling, surface albedo and imperviousness, and biotic community structure (Arnold and Gibbons 1996, McKinney 2006, Grimm et al. 2008), all of which affect ecosystem function (Chapin et al. 1997, DeFries et al. 2004). Change from undeveloped to developed land use types compromises the ability of ecosystems to provide services such as air and water filtration, flood prevention, or temperature regulation (DeFries et al. 2004, Metzger et al. 2006). Provision of cultural and social services may also be impacted, including changes in social equity, human health, and cultural heritage (Chiesura 2004, Fuller et al. 2007, Schaich et al. 2010). Given the complexity of land use systems (Costanza 1996, Green and Sadedin 2005, Liu et al. 2007), some impacts of land use change will be unpredictable, but trade-offs will undoubtedly exist between competing ecosystem services across differently managed land use types (DeFries et al. 2004, Walker et al. 2004, Foley et al. 2005).

In the face of intense and rapid landscape change, it is important to understand how the attitudes and actions of individuals and societies affect the persistence of biotic communities, as well as the potential feedbacks that may encourage further change. The overarching aim of my dissertation research is to improve our understanding of the pattern and process of landscape change in urbanizing environments. I studied the influence of human decisions on the environment, and the reciprocal influence of the environment on human decisions, within the rapidly expanding Charlotte, North Carolina metropolitan region. I examined these phenomena in three distinct steps focusing on 1) the pattern of future urban and rural development resulting from different land use policies, 2) the process of change beginning with individual land management decisions, and 3) the potential for changing markets for natural resources to influence future decision making. Each of these steps provided the framework for a single dissertation chapter and was designed to become its own publishable manuscript.

In chapter one, I used the FUTure Urban-Regional Environment Simulation (FUTURES) model to compare urban and rural development patterns that arise from different conservation-based planning policies. I analyzed the patterns resulting from each scenario to understand how these policies may impact natural resources and regional conservation priorities. This enabled me to assess the trade-offs between different conservation goals under different planning scenarios.

While many land change models such as FUTURES predict transitions based on environmental and socio-economic indicators, the process of land conversion often begins with an individual landowner's complex decisions regarding management of their land. In chapter two, I transitioned into research focusing on how the process of land use change is driven by individual landowner decisions. In order to capture this process, I created a unique data set that couples individual landowner surveys with field and remotely sensed data pertaining to those individual's properties. I used these data to test hypotheses about the direct and indirect influences of social and environmental factors on landowners' decisions regarding land management.

The expanding global market for biofuels is creating new demand for biomass resources and is having a substantial influence on local landscapes. In chapter three, I build on results from chapter two to understand how landowners' decisions may change as markets for woody biomass present them with new alternatives for managing their forested properties. I used a stated preference survey to gauge the landowners' receptivity to producing biofuel feedstocks under a set of potential management scenarios and to understand how changes in their management decisions could impact forest resources and landscape composition.

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CHAPTER 1: SIMULATING URBANIZATION SCENARIOS UNDER VARIOUS CONSERVATION-BASED PLANNING POLICIES REVEALS TRADE-OFFS BETWEEN DISPARATE CONSERVATION GOALS

1.1 Abstract

Increases in population and per-capita land consumption continue to create conflicts between demands for development and conservation of natural resources. Spatially explicit simulation models of land use and land cover change are powerful analytical tools that can be used to assess the influence of alternative urbanization patterns on conservation priorities. Using the FUTure Urban-Regional Environment Simulation (FUTURES) model, we compared current trends in development to scenarios based on various conservation-planning policies that alter the spatial distribution of development to align with conservation goals without hindering growth. We analyzed scenario outcomes to assess how future development may conflict with regional conservation priorities and influence landscape composition. Our results indicated that if current trends continue, conflicts between development and the protection of natural resources are inevitable. Alternative planning scenarios revealed that trade-offs exist between the conservation of priority resources and the preservation of landscape connectivity resulting from different conservation planning policies. For example, scenarios that preserved conservation targets near urban areas resulted in increased fragmentation of forests and farmlands in rural areas. The analyses of these land change

scenarios provided an important avenue for the exploration of unexpected landscape-level impacts of future development on conservation goals.

1.2 Introduction

Increases in population and per-capita land consumption continue to drive land use changes that alter biodiversity patterns and ecosystem function (Foley et al. 2005, McKinney 2006, Grimm et al. 2008, Aronson et al. 2014). In the case of urbanization, growth within and on the outskirts of cities frequently overlaps with locations rich in biodiversity and natural resources (Chapin et al. 1997, Ricketts and Imhoff 2003, McDonald 2008). In addition to direct resource loss, the sprawling land use patterns that are common in many growing metropolitan regions of the United States cause increased landscape fragmentation (Miller and Hobbs 2002), which can inhibit the movement and dispersal of plant and animal species.

Although the establishment of protected areas remains a primary fixture of biodiversity conservation planning, this method protects only the current distribution of species and does not account for the dynamic nature of species distributions (Pressey et al. 2007, Rands et al. 2010). Maintaining ecological connectivity within human modified landscapes has been proposed to encourage the movement and persistence of species, particularly under the threat of changing climate (Krosby et al. 2010). Additionally, improved quality of landscapes outside of protected areas can be important to species persistence (Prugh et al. 2008). Slowing global biodiversity loss will require approaches that combine the establishment of protected areas with other strategies that incorporate landscapes used and modified by humans, including specific attention to landscape patterns (Naughton-Treves et al. 2005, Reyers et al. 2012). To achieve these goals, regional planners will need information about how landscapes may change under different planning policies and to discover unexpected impacts to social, economic, and environmental systems.

Simulation models of land use and land cover change are powerful analytical tools that can address challenging policy issues associated with environmental pressures from rapid urbanization (Veldkamp and Verburg 2004). These models enable scientists, planners, and policy makers to create and visualize trajectories for future development that result from alternative planning scenarios (Baker et al. 2004, Swart et al. 2004). The results of scenario analysis can provide a starting point for discussion of alternatives (Checkland 1995, Peterson et al. 2003), broadening perspectives (Peterson et al. 2003, Xiang and Clarke 2003), and building consensus among stakeholders (Costanza 1996). Scenario analysis can be an effective tool for conservation planning, with applications that include assessing potential impacts of landscape change to biodiversity (Menon et al. 2001, Theobald and Hobbs 2002, Gude et al. 2007), addressing threats to protected areas due to development (Theobald 2003), and understanding how future development patterns influence landscapes (Swenson and Franklin 2000, Conway and Lathrop 2004).

The application of conservation planning scenarios in land change modeling is often implemented by treating priority areas as protected, essentially removing them from eligibility for development (Conway and Lathrop 2004, Gude et al. 2007). However, full protection of all priority resources is highly unlikely in urbanizing areas where development is outcompeting other land use types, decreasing the effectiveness of purchasing land for conservation due to increasing costs (Newburn et al. 2005). As an alternative to land acquisition for full protection, regulatory or policy based approaches could be introduced, reducing the negative consequences of urban development to conservation priorities without hindering growth (Brueckner 1997, Mayer and Somerville 2000). Protection could also be incentivized through payment for ecosystem services (BenDor and Doyle 2009), rewarding landowners that take action to preserve priority resources. These policies could discourage growth in priority areas in some cases, shifting the spatial distribution of new development to more suitable locations.

In this study, we expand on previous applications of land change modeling for regional conservation planning. Using the FUTure Urban-Regional Environment Simulation (FUTURES) model, we investigate how future development, resulting from various conservation-based planning policies, may 1) impact the conservation of priority natural resources and 2) influence landscape patterns and connectivity. FUTURES (Meentemeyer et al. 2013) is specifically designed to represent the spatial structure of urban growth, making it an ideal framework with which to assess potential trade-offs between these two conservation goals. In this application, we also introduce a development *constraint* parameter into the model that enables the inclusion of policies, such as new regulations or fees, which could infer some protection to priority resources without completely excluding those areas from future development.

1.3 Methods

1.3.1 Study System

The study extent (Figure 1), known as the greater Uwharrie region, is located within the Piedmont physiographic province of Central North Carolina, also embedded within the Charlanta mega-region (Florida et al. 2008). It lies at the intersection of three rapidly expanding metropolitan areas: Charlotte, the Research Triangle (Raleigh, Durham, Chapel Hill), and the Piedmont Triad (Greensboro, Winston-Salem, High Point). Unplanned expansion of these cities is of particular concern to land managers and conservation practitioners due to a culture of strong property rights and very few regulations in place for protecting the landscape features that make the Piedmont unique (North Carolina Wildlife Resources Commission 2008). The value of the natural resources in the Piedmont is often overlooked in comparison to the Appalachian Mountains to the west and the Coastal Plain to the east. However, it is a highly productive and diverse eco-region, home to numerous endangered or threatened species, natural heritage areas, and exceptional aquatic resources (North Carolina Natural Heritage Program 2013).

1.3.2 Regional Conservation Priorities

Conservation priorities in the greater Uwharrie region have been identified and mapped by the North Carolina Wildlife Resources Commission (NCWRC; 2008). Priority resources are divided into two tiers. Tier one resources extend across a total of 206,976 ha within the nine county study region and include features that are highly sensitive to development (Figure 2): significant natural heritage areas, natural heritage element occurrences, seasonal wetland pools, National Wetland Inventory wetlands, year round heron colony nesting sites, 330 foot buffers for bald eagle nesting sites, 100-200 foot stream and river buffers, and FEMA 100 year floodplain forests (NCWRC 2008). Though the resources currently have little protection, the NCWRC recommends that no future development occur in these areas. Tier two resources (not shown) are less environmentally sensitive features that are usually more widespread (extending across a total of 695,627 ha), including wildlife corridors, Piedmont prairie landforms, sparsely settled areas, smoke management buffers for controlled burns, hunting safety buffers, and native forests greater than fifty acres (NCWRC 2008). The NCWRC recommends restricted or low-density development in these areas.

1.3.3 Model Application

We applied FUTURES (Meentemeyer et al. 2013) to examine the impacts of various conservation planning scenarios on urban and rural growth in the greater Uwharrie region through the year 2032. FUTURES is a multilevel modeling framework that simulates the emergence of development patterns using three sub-models that project 1) the location (POTENTIAL sub-model), 2) the quantity (DEMAND sub-model), and 3) the spatial pattern (PGA sub-model) of urban growth using a patch growing algorithm that combines field and object-based representations of change (Figure 3). In this application, we parameterized the POTENTIAL sub-model using multilevel logistic regression of environmental, infrastructural, and socio-economic site factors associated with historical patterns of change mapped from satellite imagery. Output from this sub-model provides information about the probable location of future urban growth. We utilized the land demand sub-model (DEMAND) to extrapolate relationships between population growth and land change to determine the quantity of expected growth given future population projections. We employed the patch growing algorithm sub-model (PGA) to simulate future land change based on an iterative, stochastic site selection process and a discrete patch-based region growing algorithm designed to mimic observed spatial structures of development. The PGA can be used to integrate policy-oriented, user-defined parameters for exploration of alternative future development scenarios.

Since FUTURES is designed to capture the spatial structure of urban growth, it is an ideal model with which to assess the impacts of alternative planning scenarios on natural resource conservation and landscape fragmentation. Validation metrics for this model applied to the Charlotte metropolitan region indicated that the number and size of simulated development patches agreed with patterns of observed development, with 13.3% overall error in the quantity and location of simulated development (Meentemeyer et al. 2013).

1.3.4 Parameterization of FUTURES Sub-models

The DEMAND sub-model estimates the quantity of future development expected for each county based on trends in population growth and land consumption. We used land cover data classified from Landsat imagery to determine the amount of development within the region at four time steps: 1976, 1985, 1996 and 2006. Classification was based on the vegetation-impervious surface-soil (VIS) model and normalized spectral mixture analysis (Ridd 1995, Wu 2004), which are appropriate for heterogeneous urban-regional environments. Using ordinary least squares regression, we determined the relationship between the area of developed land (hectares) and the population for each county. The North Carolina Office of State and Budget Management (2012) currently projects population increases for the region through the year 2032. Using these population projections, we predicted status quo land demand through 2032 based on the estimated relationship between land use and population that we had observed between 1976 and 2006.

The POTENTIAL sub-model generates a site suitability map describing the probable location of future development based upon historical changes in land use. To estimate POTENTIAL, we used multilevel logistic regression to determine the relationship between socioeconomic and environmental predictor variables from the model start year (1996) and the conversion of undeveloped lands to development between 1996 and 2006. We used 1500 randomly located sample points, stratified by the binary (change to development/no change) response variable to estimate the multilevel model. We used Laplace approximation, suitable for multilevel modeling with binary response variables (Bolker et al. 2009), to estimate model parameters with the lme4 package in R (R Development Core Team 2013).

In this model, the probability that an undeveloped cell, *i*, becomes developed is determined by

$$\Pr(p_i = 1) = (e^{y_i})/(1 + e^{y_i}) \tag{1}$$

where y_i is a function of environmental, infrastructural, and socio-economic predictive site suitability variables described by

$$y_i = \alpha_{j[i]} + \sum_{h=1}^{n} \beta_{j[i]h} x_{[i]h} \tag{2}$$

where, for *i* undeveloped cells and varying across *j* groups (*i.e.* the level), α is the intercept, β is the regression coefficient, *h* is a predictor variable representing conditions in year 1996, *n* is the number of predictor variables, and *x* is the value of *h* at *i* (Gelman and Hill 2007). We included a dynamic development pressure, *dp*, predictor variable in the model, described by

$$dp_i = \sum_{k=1}^{n_i} (State_k \,/ d_{ik}^{\alpha}) \tag{3}$$

where $State_k$ is a binary variable indicating whether or not the k^{th} neighboring cell is developed, d_{ik} is the distance between cell i and the k^{th} neighboring cell, α is a coefficient that controls the influence of distance between i and k, and n_i is the number of neighboring cells with respect to cell i. This variable accounts for the effect of existing development on change, with more proximal development having a stronger influence as controlled by α. The value of α was determined by running the statistical analysis for values of α ranging between one to one hundred and choosing the value that results in peak model performance based on likelihood profile estimates (Hilborn and Mangel 1997, Meentemeyer et al. 2008). We included "county" as the group level indicator in the multilevel model to account for non-stationary processes inherent across jurisdictional boundaries (Fotheringham and Brunsdon 1999). From these model estimates (Table 1) the POTENTIAL sub-model creates a site suitability surface with values ranging from 0-1 with high values indicating a greater chance of becoming developed. Prior to fitting the multilevel model, we selected a parsimonious set of predictor variables from the initial list of hypothesized site suitability factors (Appendix A) by testing all possible regression models and choosing the model that resulted in the lowest AIC score.

We used the PGA to simulate development patterns from the starting state in 1996 through the year 2032 at one-year time intervals. The PGA algorithm stochastically allocates seeds for development across the POTENTIAL site suitability surface at the cell level. The survival and growth of each development seed is challenged using Monte Carlo simulation. Seeds that land in a location with development potential greater than a random number (0-1) survive the challenge and grow into discrete patches of development. This seed allocation process continues until the estimated DEMAND for development is met. The existence of newly allocated development is accounted for at each interval by updating the development pressure indicator variable and the site suitability (POTENTIAL) surface. The PGA *patch size* and *patch compactness* parameters were calibrated such that the empirical and simulated distributions of development patch sizes and shapes for the time period of 1996-2006 were in agreement. Calibration was conducted on a single county within the study area (Cabarrus County) according to methods followed by Meentemeyer and others (2013). Water bodies, land set aside for conservation, and previously developed areas were masked from the allocation process. For each of the following scenarios we ran fifty-five stochastic simulations. Based on prior model applications, fifty-five runs were expected to adequately capture model variation while limiting computation time.

1.3.5 Scenarios

In addition to a status quo growth scenario, we formulated eight alternative scenarios aimed at representing various conservation policies based on the regional-scale recommendations found in the NCWRC's Green Growth Toolbox (GGT). The GGT outlines specific conservation targets (including tier one and tier two resources) and provides suggestions for limiting the environmental impacts of development at both local and regional levels (NCWRC 2008). The alternative scenarios included development exclusion, development constraints, reducing demand, and encouraging infill (described below). In addition to each of these individual scenarios, we formulated four scenarios based on all combinations of development constraint, reduced demand, and infill parameters.

1.3.5.1 Status Quo Growth

We calibrated the model to reproduce the quantity, location, and pattern of growth expected based on trends in landscape change that occurred between 1996 and 2006 (as described in section 1.3.4). The status quo growth scenario was based on a continuation of these trends in urban and rural development without altering any model parameters. This scenario served as a benchmark for comparison to the following conservation scenarios.

1.3.5.2 Development Exclusion

The NCWRC recommends that development be completely excluded from all areas where tier one resources exist. In this scenario, we simulated development based on this policy of exclusion, making all tier one resources ineligible for development and holding other model parameters constant. However, in order for these patterns to be realized in the landscape, all of these areas would have to be protected from development via land acquisition or conservation easement. We realized that complete protection of these resources is unrealistic and thus also designed the following development constraint scenario.

1.3.5.3 Development Constraint

In order to minimize impacts to specific priority resources, local to regional governments can increase the cost of development through policy based mechanisms such as impact fees or increased regulation (Gyourko 1991, Mayer and Somerville 2000). To examine the possible effects of these types of land use policies, we built an optional development *constraint* parameter into the PGA, allowing the user to weight the POTENTIAL site suitability surface to increase or decrease the likelihood of development in priority areas. This modification to the PGA framework can be used to adjust the probability of development based on any set of land use goals. This approach is likely more realistic than simply eliminating a priority area from contention, as private property rights and high costs would prevent full protection for a given resource.

We conducted a sensitivity analysis to assess the influence of the *constraint* parameter on model outcomes by varying the value of the parameter (between 0 and 1, by 0.1) for tier one resources and quantifying the reduction in conflict (overlap) between simulated development and these conservation priorities (Figure 4). For the development constraint scenario, we set this parameter at 0.6, which would equate to a mean 73% decrease in conflict across 55 simulations with very limited variation between runs (mean conflict = 70,110 ha, SD = 1454). We applied the parameter to all locations where tier one resources exist, holding all other model parameters constant. This planning trajectory was expected to reduce the impacts of development to tier one resources but potentially increase landscape fragmentation by placing development in theoretically more suitable areas.

1.3.5.4 Reduced Demand

Current trends in urban expansion indicate an increase not only in population, but also in per-capita land use. While not explicitly stated as a green planning strategy recommended by the NCWRC, reduction of per-capita land consumption has the potential to reduce conflict between future development and priority resources, as well as limit the fragmentation of forest and farmland. We implemented a reduced per-capita land consumption scenario by altering the DEMAND for development, here assuming a 50% decrease in the amount of developed land per person, while holding other model parameters constant. The resulting overall reduction in new development was expected to limit both the loss of high priority resources and landscape fragmentation.

1.3.5.5 Infill

Smart growth incentives often encourage infill development near existing urban areas and infrastructure via zoning policies and development ordinances. Promoting infill will discourage forest and farmland fragmentation, but may heavily impact the natural resources found near cities. The infill scenario is implemented in the model by adjusting the optional *incentive* parameter in the PGA, which controls the influence of the development POTENTIAL surface. Here we adjusted the *incentive* parameter to encourage infill development – effectively raising the initial value of development POTENTIAL to the power of two – while holding all other model parameters constant. Encouraging infill development was expected to limit the fragmentation of urban and rural landscapes, but also result in the loss of green space and high priority resources within urban areas.

1.3.6 Analysis of Simulation Results

For each scenario, we identified locations where the NCWRC's conservation priorities (tier one and tier two) overlapped with simulated development and quantified the total amount of conflict. We assessed the spatial distribution of conflict with tier one resources by analyzing the relationship between development pressure (see equation 3) and the probability of conflict across simulations. To quantify this relationship, we mapped the percentage of times each location was developed across all simulations for each scenario. We then used a random sample of 1000 points to plot this probability against the observed development pressure of the starting state (1996) within tier one areas. A strong positive relationship would indicate that conflict is more likely in urban areas – *i.e.* the chance of a cell being simulated as developed increases with higher development pressure.

We also examined the landscape patterns that emerged from each scenario, quantifying the number, average size, and total area of patches for the entire landscape and each of three land cover classes: development, farmland, and forest land. The developed land cover class was composed of observed development from the year 1996 (mapped as described in section 1.3.4) and all simulated development through the year 2032. Farm and forested land cover were mapped from the 1992 National Land Cover Dataset (Vogelmann et al. 2001); we aggregated deciduous, evergreen, and mixed forest into a single forest class, and pasture/hay and row crops into a single farmland class. We calculated all class and landscape metrics using a four neighbor rule in FRAGSTATS (McGarigal et al. 2012).

1.4 Results

Under status quo conditions, developed area was predicted to increase by 229% between 1996 and 2032. This corresponded to a 21% loss in farmland and 14% loss in forest land across the study area. Of the additional 168,863 ha of land expected to be developed in the region under status quo conditions, approximately 23,484 ha would conflict with tier one resources and 29,550 ha would conflict with tier two resources. Representative output from each of the first five scenarios is shown in Figure 5. Analysis of the simulation results revealed differences in landscape connectivity (Table 2; see also Appendix B) and impacts to priority resources (Figure 6) across scenarios and in comparison to the status quo scenario, described in more detail below.

In the development exclusion scenario, there was a complete elimination of conflict with tier one resources (as prescribed) and a 3% increase in conflict with tier two resources as compared to the status quo. Farmland area decreased by 2% but forested area was relatively constant. There was evidence for increased landscape fragmentation in this scenario with a 3% increase in the number of patches of each forest and farmland, corresponding to decreases in patch area of 3% and 5% respectively. The development constraint scenario resulted in a 73% reduction in conflict with tier one resources (as prescribed) and a 2% increase in conflict with tier two resources as compared to the status quo. Resulting landscape patterns in the development constraint scenario were similar to those of the development exclusion scenario.

In the reduced demand scenario, conflict with tier one and two resources decreased by 28% and 27% respectively, when compared to the status quo scenario. The area of forest and farmland increased (5% and 7%) with corresponding increases in the number (1% and 3%) and size (3% and 5%) of patches, indicating preservation of these two land cover classes. Conflict was also reduced in the infill scenario compared to the status quo, but to a much lesser degree than in the other conservation scenarios, with a 7% decrease for tier one and a 17% decrease for tier two resources. The change in total area of forest and farmland was limited, but both classes had decreases in the number of patches (8% and 3%) and increases in patch area (10% and 4%), indicating a reduction in fragmentation.

Landscape patterns resulting from the combinations of the development constraint, reduced demand, and infill scenarios were generally consistent with an averaging of the effects (rather than strictly additive) of each scenario on its own. The greatest reduction in conflict for tier one resources (84%) was in the development constraint plus reduced demand scenario. For tier two resources, the greatest conflict reduction (39%) resulted from the scenario with a three-way combination of development constraint, reduced demand, and infill. The combination of reduced demand and infill reduced conflict more than either of those scenarios on their own. However, the development constraint plus infill scenario resulted in greater conflict for tier one resources than the development constraint scenario on its own.

The spatial distribution of conflict with tier one resources along an rural to urban gradient changed across scenarios. The Pearson correlation between the simulated probability of conflict and observed development pressure was stronger in the scenarios that included infill (correlations ranging from r=0.75-0.79), in the reduced demand scenario (r=0.68), and in the reduced demand plus development constraint scenario (r=0.66) than in the status quo (r=0.64; see also Figure 7). The correlation between simulated probability of conflict and development pressure was lower in the development constraint scenario (r=0.62).

1.5 Discussion

Our analyses indicated that continued expansion of urban and rural development into forest and farmlands will increase landscape fragmentation and conflict with priority natural resources in this region. The implementation of conservation based planning policies could reduce conflicts with priority resources and reduce landscape fragmentation without hindering growth. However, our results also demonstrated that no single scenario would minimize both conflicts and landscape fragmentation, thus policy formation will need to be based on trade-offs between these two goals.

The inclusion of policies designed to conserve priority resources (development exclusion and development constraint) revealed that preserving these areas could displace development, leading to greater fragmentation of forest and farmland, as well as increased conflict with lower priority resources. In these scenarios, we also discovered a subtle change in the spatial distribution of development from urban to more rural areas. In the reduced demand scenario, forest and farmland resources were spared, as well as areas with both tier one and tier two resources. Conflict occurred more frequently in urban areas as compared to the status quo; this is a logical result in a reduced demand scenario because development would not be expected to sprawl as far into rural areas. Fragmentation of forest and farmland was reduced in the infill scenario, however conflicts with priority resources were not reduced to nearly as great a degree as in the other conservation scenarios, indicating that this may not be a sufficient policy to protect these resources. Additionally, the spatial distribution of conflict shifted toward urban areas. This shift could threaten small pockets of resources or green space that are important to the conservation of biodiversity in urban areas. While there is no known optimal urbanization density, the loss of urban biodiversity hotspots and green spaces can substantially impact regional diversity patterns and quality of life (Chiesura 2004, Hahs et al. 2009, Aronson et al. 2014).

Combining policies from different scenarios generally reflected an averaging of the effects of each policy on its own. The pairing of reduced demand and infill resulted in additive effects, with less landscape fragmentation and conflict than in either scenario alone. The spatial distribution of conflict shifted to more urban areas – an effect that was consistent across all combinations that included the infill policy. Combining development constraint with reduced demand produced less conflict than in either scenario alone, however fragmentation increased compared to the reduced demand scenario. Combining development constraint with infill resulted in less fragmentation, but greater conflict, than in the development constraint scenario alone, and greater fragmentation with less conflict than in the infill scenario alone. This indicates that these policies may work against each other when it comes to reducing landscape fragmentation and conflicts with priority resources.

The flexible weighting scheme (development *constraint* parameter) introduced to the FUTURES modeling framework in this application enabled the examination of scenarios based on any set of priorities, with the potential to produce a more realistic representation of the land change process than simply eliminating the possibility of development from priority areas (Peterson et al. 2003, Newburn et al. 2005). However, the policies examined in these scenarios are hypothetical in nature. Understanding the actual policy features necessary to achieve results revealed by these simulations would require local assessment of the influence of such policies on development rates and patterns. Additionally, these simulations are intended to be interpreted at the regional level and are not appropriate for use in site-level planning processes (for example, planning a new neighborhood). Regional scale planning will necessitate cooperation amongst local planners and stakeholders across jurisdictional boundaries, a process that could be enhanced through the use of scenario results (Checkland 1995, Costanza 1996).

Simulating land change under these scenarios has provided an important avenue for exploring the potential landscape level impacts of future development on ecological communities and conservation priorities. FUTURES accounts not only for development demand and site suitability, but the discrete patch-based region growing algorithm also captures the spatial structure of expected growth. This allows for assessment of landscape structure and results in landscape patterns that seem realistic and tangible, and are thus more likely to spawn discussion and change among land use planners (Peterson et al. 2003, Xiang and Clarke 2003). In order to further increase relevance to regional policy formation, the conservation scenarios presented here were designed to reflect the conservation goals of the NCWRC (Peterson et al. 2003, Swart et al. 2004). These visualizations of alternatives are being used by the NCWRC to engage other community stakeholders and guide effective preservation of the region's remaining natural resources while meeting the needs of a growing population.

Our results highlight the importance of considering multiple criteria in policy formation for conservation. While we designed each conservation scenario to reduce impacts to natural resources, the effects on the conservation of priority resources and landscape fragmentation were variable. Landscape outcomes will depend on the fine balance between different land use policies. In future work, combining these analyses with assessment of the social and economic impacts expected from the scenarios would provide a more complete framework for understanding the full range of trade-offs in both social and environmental systems.

Table 1: GLMM estimates for POTENTIAL suitability surface.

Predictor Variables	Estimate	Std Error	P-value
Intercept*	0.991	0.303	0.001
Slope	-0.040	0.025	0.109
Interchanges	-0.049	0.009	<0.001
Roads	-0.613	0.086	<0.001
Municipal centers	-0.007	0.004	0.066
Development pressure	0.039	0.004	<0.001

*varies by county (std dev=0.345)

Table 2: Summary of landscape metrics for the starting state (1996) and mean metrics for each scenario at the end point of the simulation. Measurements are in hectares. Percent change from status quo is listed for all conservation scenarios.

	Starting state	SQ	DE	DC	RD	I	RD + I	DC + RD	DC + I	DC + RD + I
Developed land										
Class area	73,683	242,546	-0.1%	0.0%	-18.6%	0.0%	-18.6%	-18.6%	0.0%	-18.7%
# of patches	15,839	38,848	-0.8%	-1.4%	-6.0%	-36.8%	-37.3%	-6.8%	-37.2%	-37.7%
Mean patch area	4.65	6.24	0.7%	1.4%	-13.4%	58.1%	29.7%	-12.7%	59.2%	30.6%
Farmland										
Class area	255,952	201,259	-1.9%	-1.3%	7.4%	0.1%	7.5%	6.4%	-1.0%	6.8%
# of patches	159,186	147,635	3.2%	2.4%	2.5%	-3.3%	0.2%	4.3%	-1.5%	1.5%
Mean patch area	1.61	1.36	-4.9%	-3.6%	4.8%	3.5%	7.4%	2.0%	0.5%	5.2%
Forested land										
Class area	667,002	571,118	0.3%	0.3%	4.6%	0.9%	5.4%	4.8%	1.0%	5.5%
# of patches	104,152	99,031	3.0%	3.4%	1.3%	-8.1%	-5.2%	3.7%	-4.2%	-2.5%
Mean patch area	6.40	5.77	-2.6%	-3.0%	3.2%	9.8%	11.2%	1.0%	5.5%	8.2%
Entire landscape										
# of patches	393,386	378,726	2.9%	2.3%	2.2%	-9.0%	-5.0%	3.9%	-6.6%	-3.3%
Mean patch area	2.71	2.82	-2.8%	-2.3%	-2.2%	9.9%	5.3%	-3.8%	7.1%	3.4%

SQ = Status quo DE = Development exclusion DC = Development constraint RD = Reduced demand I = Infill

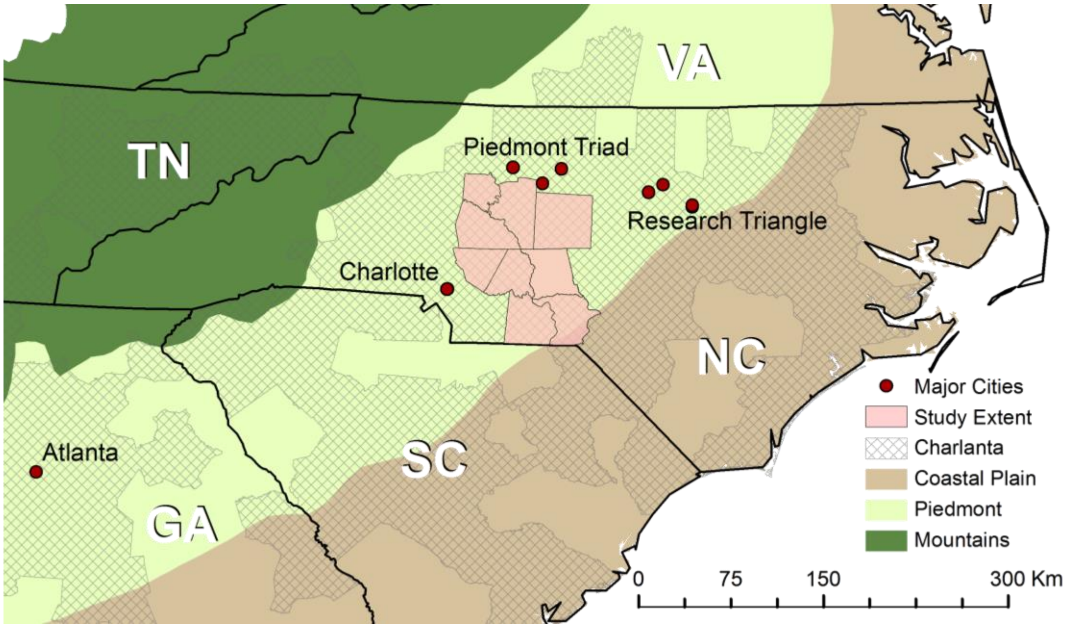

Figure 1: The study extent includes nine counties that encompass the greater Uwharrie region of the central North Carolina Piedmont at the intersection of three expanding metropolitan areas and at the center of the Charlanta mega-region.

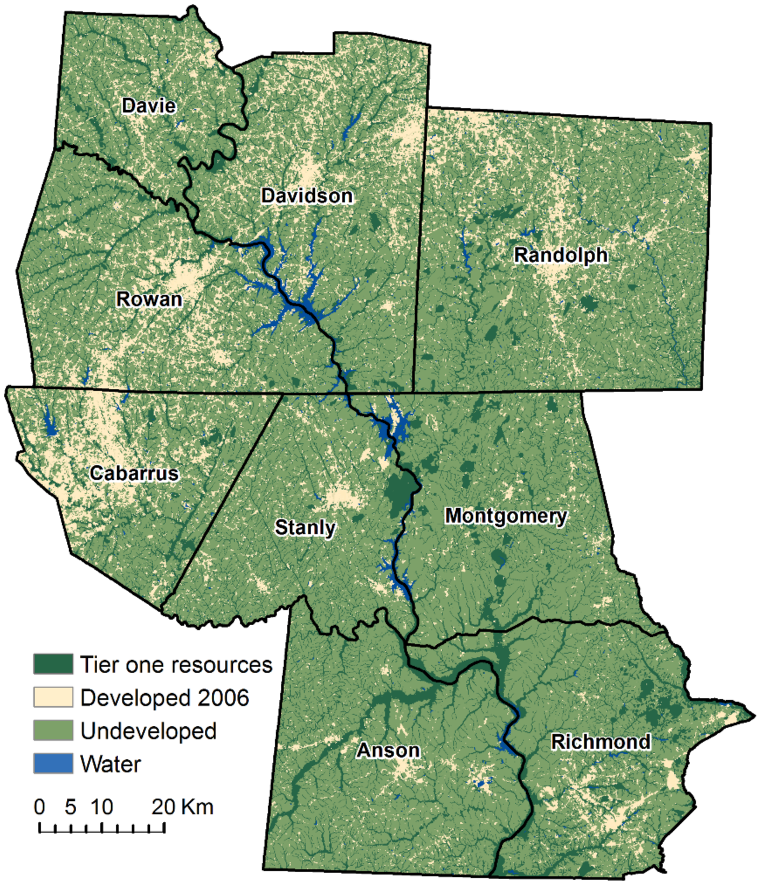

Figure 2: The nine-county region includes a mix of developed and undeveloped land use types, with tier one priority resources interspersed throughout.

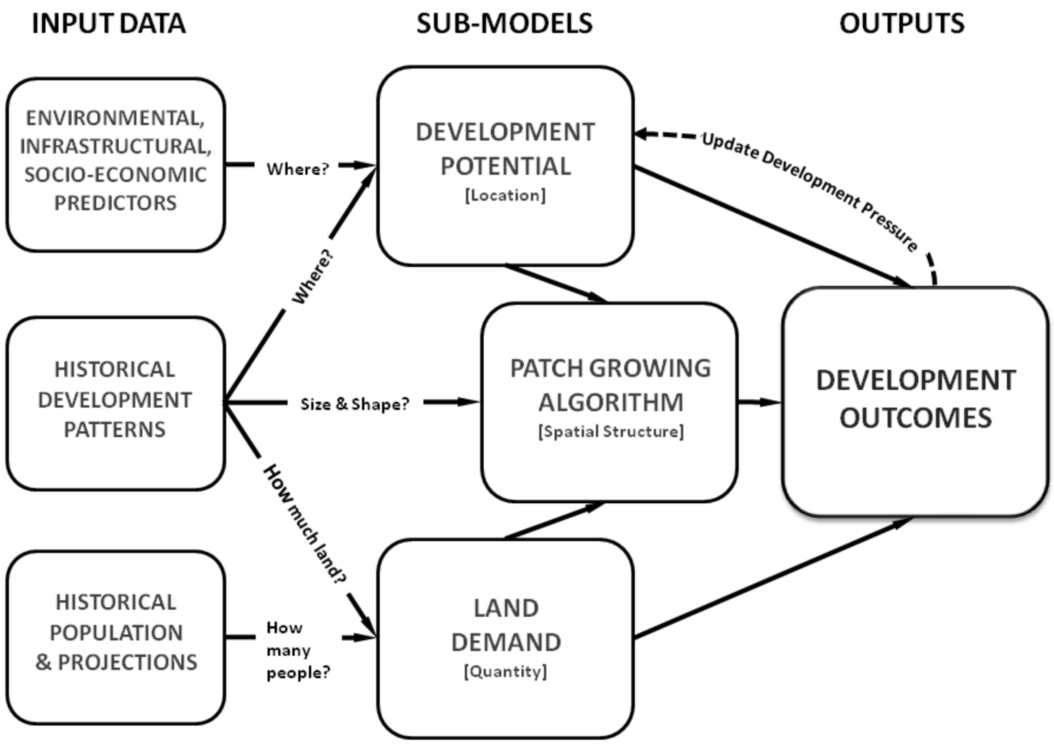

Figure 3: The FUTure Urban-Regional Environment Simulation model combines three sub-models to simulate future development outcomes (figure modified from Meentemeyer et al. 2013).

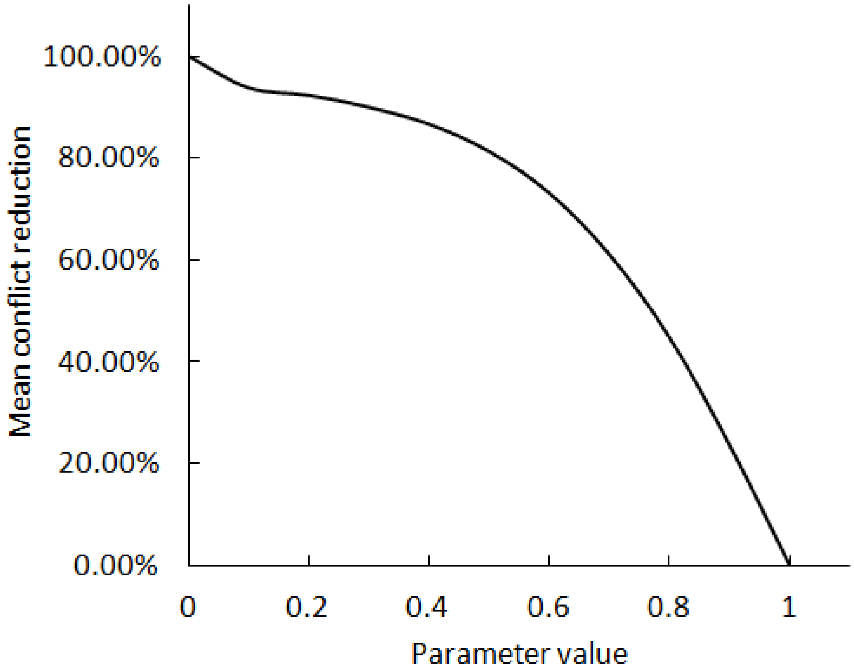

Figure 4: Results of sensitivity analysis show the influence of the development *constraint* parameter on mean conflict reduction across all simulations. The *constraint* parameter is multiplied by the initial development POTENTIAL, decreasing the site suitability as the value of the parameter decreases.

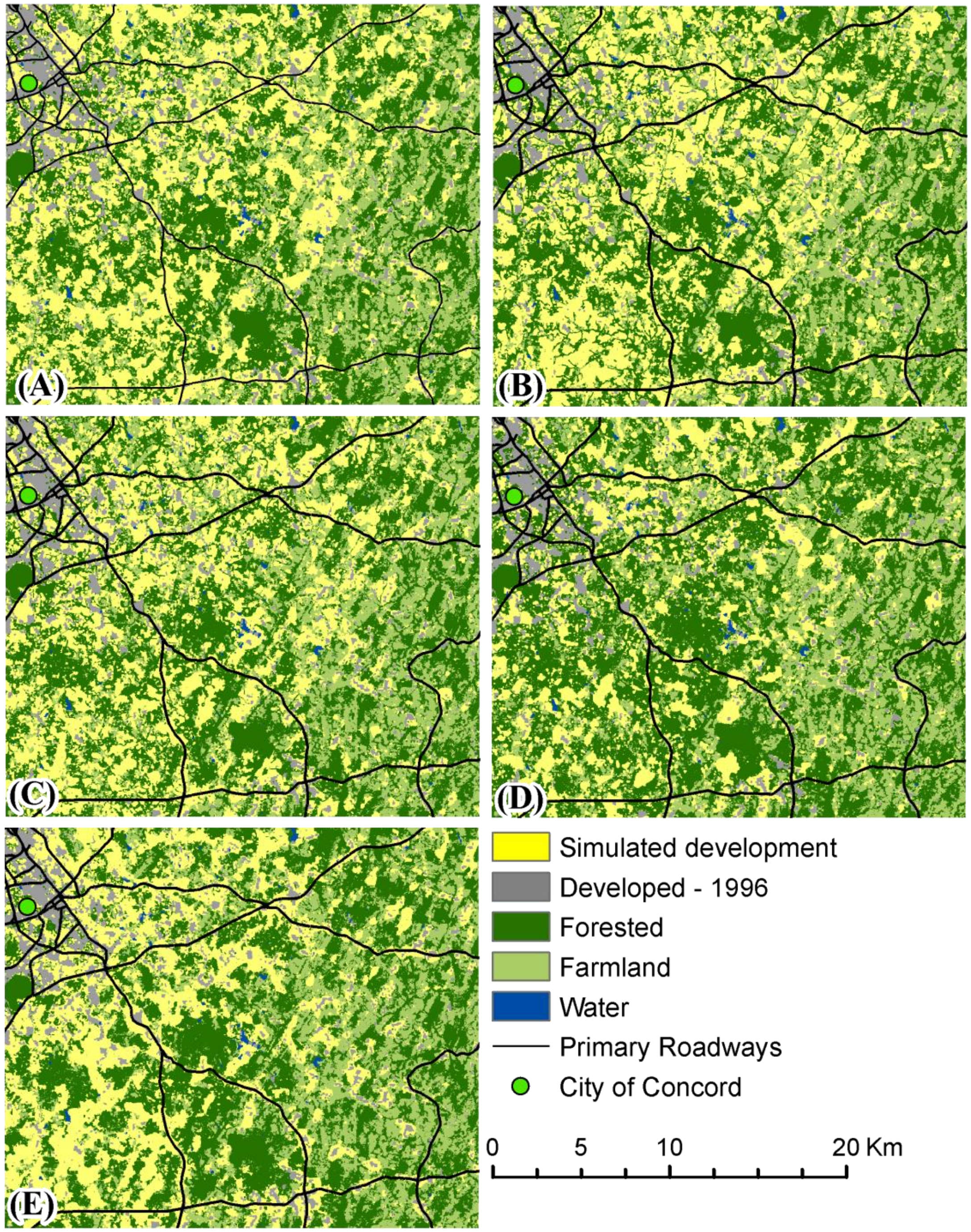

Figure 5: Representative output of a subset of the study area in Cabarrus county for the A) status quo, B) development exclusion, C) development constraint, D) reduced demand, and E) infill scenarios.

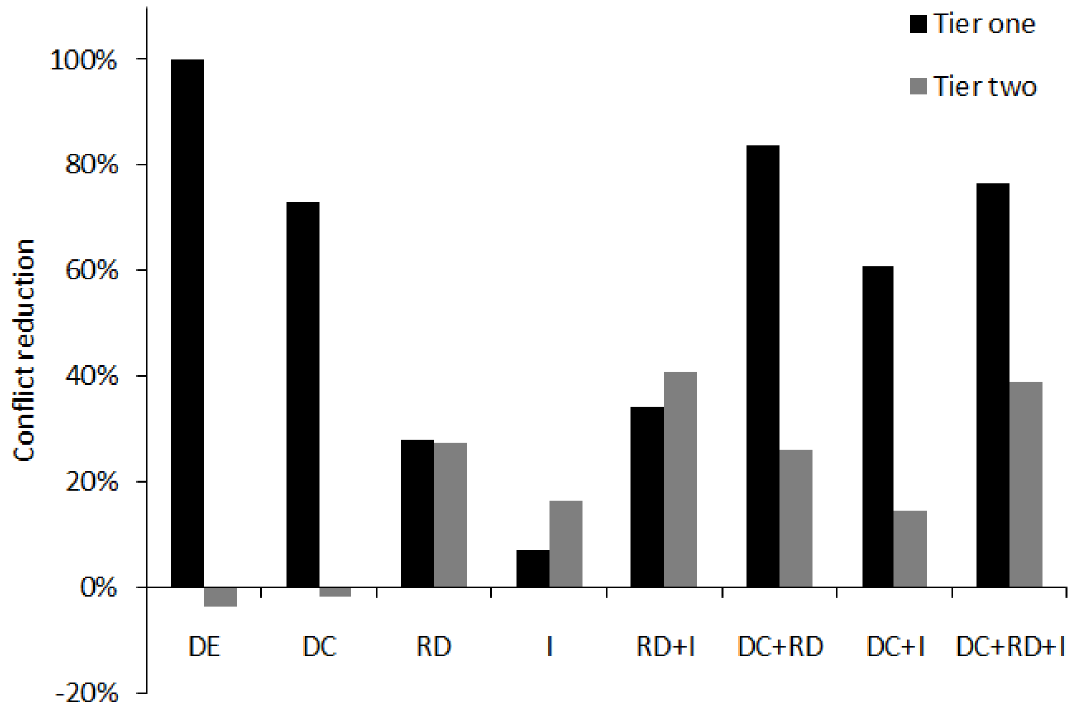

Figure 6: Conflicts between simulated development and priority resources are reduced across all conservation scenarios (compared to the status quo), with the exception of small increases in conflict with tier two resources in the first two scenarios.
(DE = Development exclusion, DC = Development constraint, RD = Reduced demand, I = Infill)

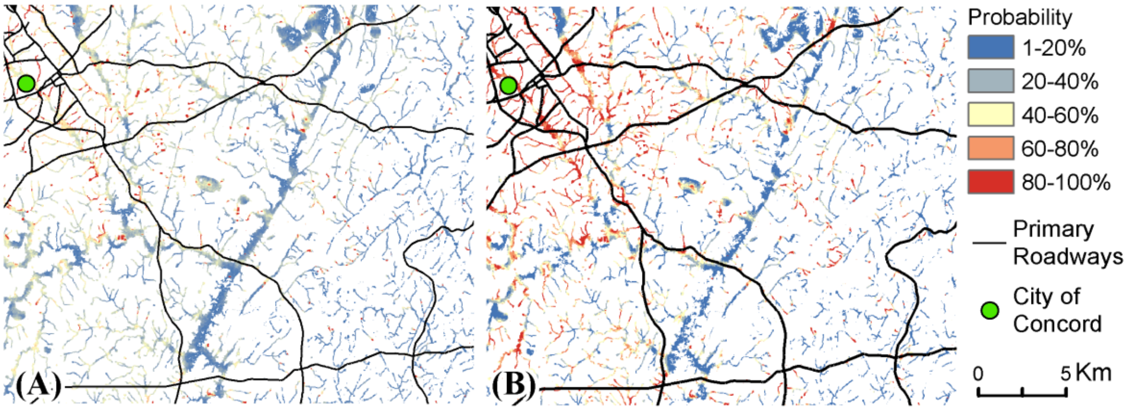

Figure 7: The spatial distribution of development probability – the percentage of times a cell is selected to be developed across all simulations – varies across scenarios. Development probability is shown for locations where tier one resources exist. Compared to the status quo (A), the development probability of tier one resources in the infill scenario (B) was more concentrated in urban areas.

CHAPTER 2: LINKING LANDOWNERS AND LANDSCAPES – EFFECTS OF ACTUAL AND PERCEIVED ENVIRONMENTS ON FOREST MANAGEMENT DECISIONS IN URBANIZING AREAS

2.1 Abstract

The process of landscape change is frequently initiated by individual decisions that then collectively influence landscape structure. In the case of privately owned forests, landscape change and fragmentation can leave individuals facing difficult decisions regarding management of their land. While personal and economic values are important factors in those decisions, the influence of the biotic environment and the landowner's perceptions of that environment remain unclear, largely due to the lack of studies that match environmental field data with social survey data. This study links ecological, social, economic, and remote sensing data from multiple scales to examine complex inter-relationships among factors influencing the decision-making processes of individual forest owners facing different levels of development pressure. We surveyed 76 land owners holding forested properties along a gradient of urbanization in Charlotte, North Carolina, inquiring about forest management, personal values, and perceptions of their forest's ecological characteristics. At each forest holding, we also established field plots to measure forest structure and woody plant diversity. Using a structural equation modeling framework, we analyzed the direct and indirect effects of measured ecological and landscape characteristics – as well as landowners' perceptions of their forests' ecology – on land management decisions after accounting for personal and economic

values. We found that the amount of surrounding farmland and perceptions of forest ecology play significant roles in landowner decision making processes, and that these factors are further influenced by the landowner's presence on their property, their sense of place, and the observed ecology of their forest. Since landscape characteristics are directly influencing decisions about forest management, there is potential for a positive feedback between landowner decisions and continued landscape change.

2.2 Introduction

Landscape change in urbanizing environments is governed by complex interactions between social and ecological systems across multiple scales (Stern 1993, Best 2002, Liu et al. 2007). When humans alter landscapes and environmental processes new environmental systems may arise that in turn further influence management decisions, creating a feedback between landscape change and decision making (Liu et al. 2007, Ostrom 2009). This process of change often begins with individual land management decisions that are guided by a wide array of social, environmental, and economic factors (Young and Reichenbach 1987, Koontz 2001, Jacobson 2002) and are additionally influenced by the individual qualities and attitudes of the landowners (Koontz 2001, Jacobson 2002, Lokocz et al. 2010). The personal values influencing landowner decisions are often place-based (Manzo and Perkins 2006, Cross et al. 2011, Lai and Kreuter 2012). For example, Lokocz and others (2010) found that place attachment is positively related to land protection and stewardship, and Gosling and Williams (2010) found that connectedness to nature is strongly related to vegetation management decisions. Landowner values and attitudes can also vary along a gradient of urbanization (Jones et al. 1999, Berenguer et al. 2005). As landscapes change, interactions between humans and their environment will also evolve, potentially leading to a different set of landowner values and decisions (Jorgensen and Stedman 2006, Lai and Kreuter 2012).

In the southeastern United States, the majority of all forested land is in individual or private, non-corporate ownership (Butler 2008). Landscape change and fragmentation threaten the persistence of private forests in this region, creating a rapidly evolving social and ecological environment that leaves individuals and families facing difficult decisions when choosing how to manage their land (Bengston 1994, Best 2002). While it is clear that individual values and economic factors play important roles in those land management decisions, few studies have assessed the effect of the environmental characteristics of a place, including the ecological features of a forest or landowner perceptions of those features, in decision making. Forest size has been shown to play an important role in management decisions (Koontz 2001, Boon and Meilby 2004), but the roles of other forest characteristics such as the type, size, or age of the trees, are understudied. Additionally, people often act in accordance with their own perceptions (Brown 2004), thus landowner perceptions of the ecology of their property may be more important than quantifiable ecological features. Our understanding of these issues is limited due to the lack of studies that couple landowner surveys with ecological field data collection.

In this study, we implemented a unique sampling design that integrates social, ecological, economic, and remote sensing data from multiple scales to examine the complex inter-relationships among factors influencing the decision making processes of individual forest owners. We used a structural equation modeling framework to test hypotheses about the direct and indirect effects of ecological values and landscape context, as well as perceptions of ecological values, on land management decisions after accounting for ownership characteristics, economic values, and personal values. Testing these relationships required a data collection method that matches individual survey data with field and remotely sensed data pertaining to those individual's properties. Creation of these individual-environmental linkages is expected to expand our understanding of landowner decision making processes compared to examining either system in isolation.

2.3 Methods

2.3.1 Study System

The Charlotte Metropolitan region (Figure 1) is rapidly growing in both population and developed area (Meentemeyer et al. 2013), making it an ideal system in which to study the social and ecological impacts of landscape change. Charlotte lies at the center of Charlanta, the third largest mega-region in the United States, stretching from Raleigh, North Carolina to Atlanta, Georgia (Florida et al. 2008). The thirteen-county combined Charlotte Metropolitan area has grown in population from 1.3 to approximately 2.4 million people over the last thirty years and is expected to increase an additional 50% by 2030 (NCOSBM 2012). The rapid population growth has transformed the landscape from predominantly rural and agricultural, to one of intense urban and suburban development. This diverse and dynamic region provides a heterogeneous environment that captures a full range of urban and rural conditions in which to study landscape change (BenDor et al., in press).

2.3.2 Modeling Framework and Estimation

We constructed a conceptual model of the parameters expected to influence private forest owners' management decisions (Figure 2). We expect that decisions are directly influenced by individual economic, ecological, and personal values, as well as landowner's perceptions of ecological values. In this model, decisions are also indirectly influenced by landscape context, owner characteristics, ecological values, and personal values. We used path analysis, a form of structural equation modeling without latent variables, to test the direct and indirect relationships indicated in the conceptual model. While multiple indicators for each construct are likely to play important roles in decision-making process, we necessarily selected or created a single indicator (Table 1) for each of the proposed theoretical constructs in order to limit model complexity.

We followed the d-separation (d-sep) procedures recommended by Shipley (2000) in order to test model fit based on k conditional independence claims of the causal graph (path diagram). This procedure relaxes the assumptions of normality in endogenous variables and the necessity for large sample sizes that are required by classical structural equation model modeling, but violated by our model. Model fit according to the d-sep test is assessed using the C statistic, which follows a chi-square distribution with $2k$ degrees of freedom and indicates poor model fit when $P < 0.05$. We modified the initial model if poor model fit was indicated or if tests of conditional independence revealed relationships not specified in the model. Once a final model was obtained, we estimated path coefficients using generalized linear models for each endogenous variable. We checked each regression model for outliers, multicollinearity, normality of residuals, and residual spatial dependence. All models and tests were conducted using R Version 3.0.1

(R Development Core Team 2013). Collection and compilation of data for each of the indicators used in the path model is described in the following sections.

2.3.3 Study Population

We mailed an invitation to participate in this study to 2500 private woodland owners within the area of interest who owned at least two hectares of contiguous forested land embedded within varying development densities (Figure 1). Contiguous forest was mapped through a fusion of Landsat and LiDAR data from 2011 that was classified by Singh and others (2012) as developed land, forested land, farmland, or water. Participating landowners' properties were distributed across six counties on the eastern side of the Charlotte Metropolitan area, capturing the urban-rural gradient for the region with both mixed deciduous and evergreen forest types. We asked landowners who held multiple forested properties within the study area to participate in reference to a single patch of forest within a single parcel. We received 143 responses and 126 complete surveys for a response rate of 5.7%. We attribute this limited response rate to the requirement that landowners sign a consent form allowing researchers access to their properties to collect ecological field data. Acceptance of a low response rate was a sacrifice we had to make in order to be able to collect in-depth field data pertaining to each individual's forest, enabling assessment of individual-environmental linkages.

2.3.4 Landowner Characteristics, Personal Values, and Forest Management Decisions

We derived three model indicators from a revealed preference survey that included questions regarding forest management decisions, personal values, and basic demographic information. The survey was administered by mail to each study participant in November 2011 and included a personalized map of the forested property referenced in the survey. This ensured that the landowners were connecting their responses to a specific forested property and that we could then link those responses to associated ecological and landscape level data pertaining to that forest. Indicator variables derived from the survey included intention to sell, presence, and sense of place.

The primary response addressed in the path model is the intention or willingness of the landowner to sell their forested property. This decision is relatively understudied, with most literature on private forest owner behaviors focusing on timber harvest or other forest management activities (Gregory et al. 2003). However the decision to sell has important implications for land use change as it will determine the future trajectory of the property (Ma and Kittredge 2011) and the majority of sales of undeveloped lands in rapidly urbanizing areas are to investors or developers (Brown et al. 1981). In our model, we based the binary intention to sell indicator on responses to three questions from the survey that asked whether or not the landowner intended to sell the property, whether or not the property was for sale, and whether or not they would sell it for their own estimation of its current real estate value.

While a number of landowner characteristics are known to influence decisions (Koontz 2001, Boon and Meilby 2004, Joshi and Arano 2009), we chose to represent the landowner's ownership characteristics with an indicator of their presence on the property. The amount of time spent on a property is likely to play an important role in influencing a landowner's sense of place and perceptions of their environment (Jorgensen and Stedman 2006, Vokoun et al. 2006). In the survey, landowners were asked how long they had owned the property, as well as approximately how many days they have seen or visited the property each year. The indicator of presence was equivalent to the product of the landowner's response to these two questions, capturing both the length of ownership and the degree of the owner’s physical presence on the property.

We selected sense of place as the indicator representing personal values. Sense of place plays an important role in how people value and act within their environments and can itself be influenced by environmental factors (Jorgenson and Stedman 2006, Cross et al. 2011). The survey included 9 questions modified from Jorgensen and Stedman (2006) assessing the landowner's place attachment, identity, and dependence regarding their woodland based on a 5-point Likert scale (see Appendix C). Using responses from all 9 of these questions, we applied principal axis factoring in SPSS Version 21 (IBM Corp. 2012) to create a single unidimensional construct representing the sense of place indicator (71% variance explained, Cronbach’s alpha = 0.949).

2.3.5 Ecological Values

We derived an ecological index from field measurements of tree size, stand age, and native plant species richness. To quantify these indicators of ecological values we measured the conditions of each landowner's forest during site visits conducted from May-October 2012. We established between three and ten 11.5m fixed-radius sampling plots within each landowner's forest. We used a random point generator in GIS to map plot locations at a plot density of approximately one plot per hectare. Within each plot, we inventoried all woody plant species that were greater than 12.7cm diameter at breast height (DBH; 1.3m), recording species identity and DBH. Following Forest Inventory Analysis guidelines (U.S. Department of Agriculture – Forest Service 2010), we also selected a site tree representative of the plot, from which we took an increment core to determine the approximate age of the forest. Within each plot, we established three 1.5m radius sub-plots located systematically at 3m, 4.5m, and 6m from the center of each plot in the directions of 0°, 120°, and 240° respectively. Within these sub-plots, we recorded the identity and abundance of native woody shrubs and vines. From these measurements, we quantified the average DBH of trees, the average age of trees, and the total number of native woody plant species present within the forest. The ecological index was equal to the sum of these three variables (scaled by their standard deviations). Due to time constraints, our sampling of ecological data was limited to 86 of the original 126 landowners.

2.3.6 Perceptions of Ecological Values

We constructed a perceptions index that would be equivalent to the ecological index, but representative of the landowners' perceptions of ecological value rather than field measured indicators. Concurrent with field data collection, study participants completed a field questionnaire that assessed their perceptions of their forest's structure (stand age and average tree diameter) and woody plant species richness. These were measured using a five-point scale with higher values indicating older stands, larger trees, and more diversity. We created the perceptions index based on these three variables following the same methods used to construct the ecological index. We received 76 complete field questionnaires from the sample of 86 landowners from whom we collected ecological field data.

2.3.7 Landscape Context and Economic Values

Using the previously described land cover data, we quantified landscape composition surrounding each landowner's forest within a two-kilometer radius. Since rural communities and landscapes are part of the environmental heritage of this area (Hart

2008), we focused specifically on the amount of surrounding farmland to represent landscape context. To represent the economic value of the land, we extracted the total economic value of the parcel under study from county-level parcel data within a GIS.

2.4 Results

Based on responses from the revealed preference survey, ecological field data collection, and the field questionnaire, we were able to compile complete data sets for a total of 76 landowners and their forested properties. These landowners were predominantly male (68%) and an average of 66 years of age (SD=12). All of the landowners reported that they had completed high school and 85% had some college, a statistic that identifies this population of landowners as better educated than woodland owners nationwide (Butler 2008). The average landowner had owned their property for 24 years (SD=14) and was present at the property 230 days out of the year (median=360 days, SD=166). The forested properties owned by these landowners ranged in size from 2 to 51 hectares (mean=7.8ha). Trees on those properties were an average of 59 years old (SD=19) and 25cm DBH (SD=5), with an average of 31 native woody plant species present (SD=6). Twenty of the landowners indicated an intention or willingness to sell their forested properties.

According to the d-sep tests, the initial model did fit the data (C=22.36, df=18, P=0.22). However, tests of conditional independence revealed that the intention to sell was directly influenced by both landowner presence and surrounding farmland. Therefore, the original model was modified to include these two paths, resulting in the final model (Figure 3; Table 2; C=11.72, df=14, P=0.63). Model estimates (Table 3) indicated that the intention to sell a property is directly and significantly ($P<0.1$)

influenced by increased perceptions of ecological value, increased economic value of the property, reduced presence on the property, and smaller quantities of surrounding farmland. Landowners' perceptions of ecological values increased with the measured ecological values and with increasing sense of place, while sense of place increased with increasing presence on the property. These paths also reveal indirect, positive effects of presence, sense of place, and ecological values on the intention to sell (Table 4, Figure 3).

2.5 Discussion

In this study, we have demonstrated the importance of considering multiple types of values when evaluating land management decisions. Economic values, while important, had a lesser effect on a landowner's intention to sell their property than the landowner's perceptions of ecological values, their presence on that property, and the surrounding landscape context. Through the use of a path analytical model, we were able to reveal indirect relationships that would not otherwise be apparent through the use of traditional regression models. For example, while a landowner's presence on their property has a strong negative effect on their intention to sell that property, this effect is somewhat weakened by the positive path from presence through sense of place and perceptions of ecological values to the intention to sell. Additionally, while personal and ecological values did not have a direct effect on the intention to sell, they both had indirect effects that were mediated by perceptions of ecological value. Surprisingly, we found no effects of the surrounding landscape context on any of the individual values described in the model (ecological, perceptions, personal, or economic), though the use of the d-sep procedure did allow us to discover a direct effect of the landscape context on the intention to sell.

While most of the relationships among the model variables were in the direction we expected, one relationship did not follow our hypothesized model. It was expected that as perceptions of ecological values increased, the intention to sell would decrease, an effect indicating that landowners who felt their land had larger, more mature trees and greater biodiversity would be less likely to sell that property. We found that the opposite was true. Rather than finding them more appealing to keep, landowners were more likely to sell properties if they perceived them as having greater ecological value. The size of trees on the property is correlated with tree volume and thus the extrinsic value of the timber, perhaps adding to the value of the property if sold. While direct negative influences of surrounding farmland and landowner presence on the intention to sell were not initially part of the proposed model, these relationships do fit within our expectations. More farmland in the surrounding landscape would be indicative of greater persistence of rural character, which was expected to be of value to the landowners. Absentee landowners were also expected to be less attached to the property and thus more likely to sell.

Overall, model results support the hypothesis that the biotic environment, landscape context, and perceptions of those environments influence landowner decisions. While personal and economic values remain important contributors to decision-making processes, the roles of biotic structure of the environment and its surroundings should also be considered. The inter-relationships among these different types of values may be important to other land management decisions, such as managing for timber or conservation of biodiversity, all of which have an important role to play in natural resource management. Our results also support the hypothesis that landowner perceptions of value are more important than quantifiable indicators of those values and should be further explored. The influence of perceptions of landscape context may be of particular importance as some residents and landowners have negative perceptions of landscape change (Lokocz et al. 2010, Soini et al. 2012) and could decide to sell their land due to related impacts (Murray and Nelson 2005).

The direct influence of landscape context on decision-making found in this study suggests an important feedback where landscapes influence decisions that in turn affect landscape change. As farmland disappears from this urbanizing environment, those landowners that value the rural character of their communities may be inclined to give up and go elsewhere, perpetuating the cycle of urbanization and contributing to the loss of forested land. The individual decisions of these small private forest owners will collectively shape the structure of the landscape. Additionally, as landscapes continue to change, the relationships between people and their environments may also be altered leading to different landowner values and decision-making processes (Jorgensen and Stedman 2006, Lai and Kreuter 2012).

Through linking of individual and environmental data in a structural equation modeling framework, this study revealed factors contributing to landowner decisions pertaining to their own land which is fundamental to understanding land use in urbanizing environments. However, the implementation of these unique data linkages presented us with numerous challenges, including low landowner response rates. Additional studies are needed that explore techniques for improving response rates and confirming the relationships found in this sample population. We should also explore the use of additional data from remote sensing to quantify ecological indicators or continue to focus on landowner perceptions, rather than observed ecological values. These could be practical alternatives for understanding individual-environmental linkages without the increased burden of ecological field data collection.

With increasing competition for land, progress toward sustainable land use will be heavily dependent upon local relationships between individuals and communities and their environments (Stern 2000, Uzzell et al. 2002, Ostrom 2009). Understanding the complex relationships between landowner perceptions, values, and management decisions and how those relationships vary within socio-ecological context will contribute to a greater comprehension of land use systems. With this knowledge we will also have greater insight into how landowners might alter their decision making processes amid social and environmental change. Improved awareness of these processes will aid community outreach organizations and governments in planning for change, keeping in mind that landowners will be more receptive to initiatives and programs that are in line with their values (Gosling and Williams 2010), including the desire of landowners to maintain place and environmentally based relationships with their land (Lai and Kreuter 2012).

Table 1: Indicator variables representing theoretical constructs from conceptual model of landowner decisions.

Model parameter	Indicator variable	Data source	Description
Management decisions	Intention to sell	Revealed preference survey	Intention to keep (0) or sell (1) forest
Ecological values	Ecological index	Derived index	Sum of scaled* ecological variables (E1:E3)
	(E1) Tree diameter	Field data	Average diameter of trees on property
	(E2) Stand age	Field data	Average age of trees on property
	(E3) Species richness	Field data	Number of woody plant species present on property
Perceptions of ecological values	Perceptions index	Derived index	Sum of scaled* perception variables (P1:P3)
	(P1) Perception - tree diameter	Field questionnaire	Landowner perception of tree diameter
	(P2) Perception - stand age	Field questionnaire	Landowner perception of stand age
	(P3) Perception - species richness	Field questionnaire	Landowner perception of species richness
Personal values	Sense of place	Derived factor	Factor score derived from 9 survey questions
Economic values	Parcel value	GIS parcel data	Total economic value of parcel that forest falls within
Landscape context	Surrounding Farmland	GIS land cover data	Farmland within a 2km radius of landowner's forest
Owner characteristics	Presence	Derived index	Product of years owned and days seen (O1:O2)
	(O1) Years owned	Revealed preference survey	Number of years landowner has owned property
	(O2) Days seen	Revealed preference survey	Average number of days per year landowner sees property

*scaled variables were divided by their standard deviations

Table 2: Results of d-separation tests of conditional independence for the final model.

Independence claims	t value	Probability
6_‖_7	-0.727	0.470
5_‖_6 {7}	0.533	0.595
2_‖_7 {6}	-0.414	0.680
4_‖_5 {6,7}	-0.330	0.742
2_‖_5 {6}	1.337	0.185
3_‖_5 {2,4,6,7}	-1.234	0.221
2_‖_4 {6,7}	0.688	0.494

C = 11. 72, df = 14, P = 0.63

Variables (1) Intention to sell, (2) Ecological index, (3) Perceptions index, (4) Sense of place, (5) Parcel value, (6) Surrounding farmland, and (7) Presence.

Table 3: Path coefficients for final model. Each variable that serves as a response in the path model is listed at the left.

Response variable	Predictor variables	Standardized estimate	Std error	P-value	
Intention to Sell	Ecological Index	-0.358	0.303	0.237	
	Sense of Place	-0.260	0.304	0.392	
	Perceptions Index	0.705	0.379	0.063	*
	Parcel Value	0.566	0.303	0.062	*
	Presence	-0.818	0.375	0.029	**
	Surrounding Farmland	-0.579	0.322	0.072	*
Perceptions Index	Presence	0.164	0.168	0.331	
	Ecological Index	0.363	0.164	0.030	**
	Surrounding Farmland	0.136	0.165	0.413	
	Sense of Place	0.318	0.168	0.062	*
Ecological Index	Surrounding Farmland	0.036	0.058	0.533	
Sense of Place	Presence	0.202	0.112	0.075	*
	Surrounding Farmland	-0.060	0.112	0.594	
Parcel Value	Surrounding Farmland	-0.098	0.109	0.371	

*$P < 0.1$, **$P < 0.05$

Table 4: Summary of all direct, indirect, and total effects from the final path model.

Response variable	Predictor variables	Direct effects	Indirect effects	Total effects
Intention to Sell	Ecological Index	-0.358	0.256	-0.102
	Sense of Place	-0.260	0.224	-0.036
	Perceptions Index	0.705	-	0.705
	Parcel Value	0.566	-	0.566
	Presence	-0.818	0.108	-0.710
	Surrounding Farmland	-0.579	0.040	-0.539
Perceptions Index	Presence	0.164	0.064	0.228
	Ecological Index	0.363	-	0.363
	Surrounding Farmland	0.136	-0.006	0.130
	Sense of Place	0.318	-	0.318
Ecological Index	Surrounding Farmland	0.036	-	0.036
Sense of Place	Presence	0.202	-	0.202
	Surrounding Farmland	-0.060	-	-0.060
Parcel Value	Surrounding Farmland	-0.098	-	-0.098

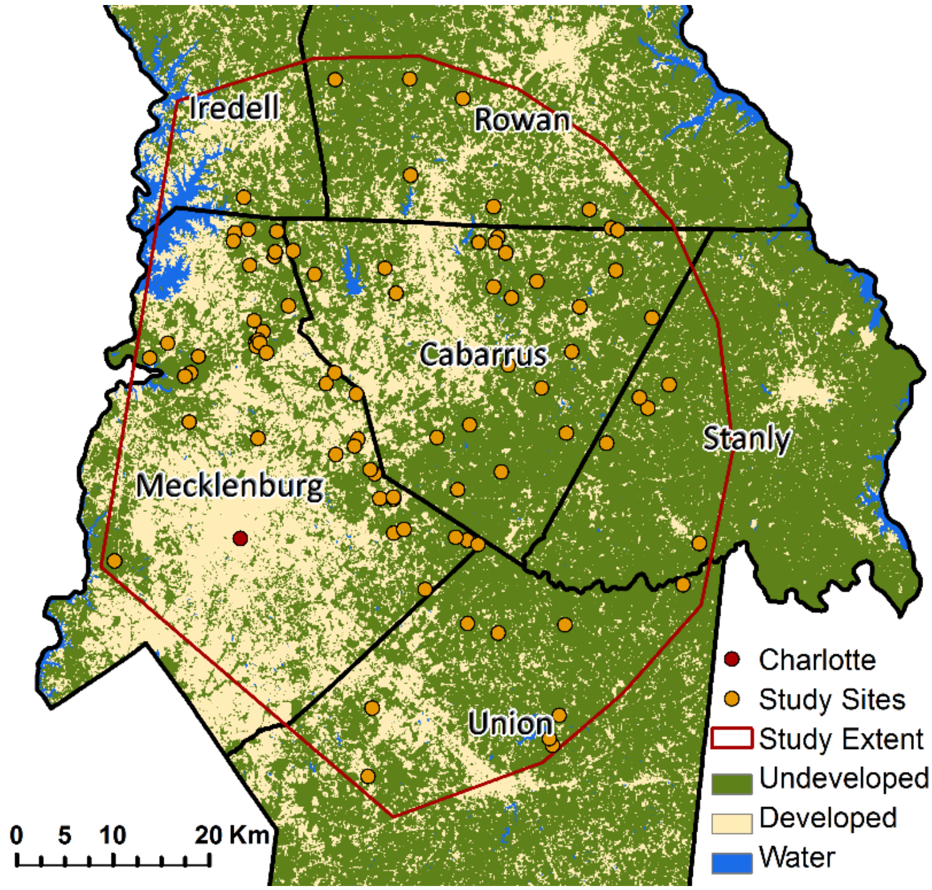

Figure 1: Study sites are located across a six county region within and on the outskirts of Charlotte, NC. Sites are distributed at varying distances from developed and undeveloped (forest and farmland) areas.

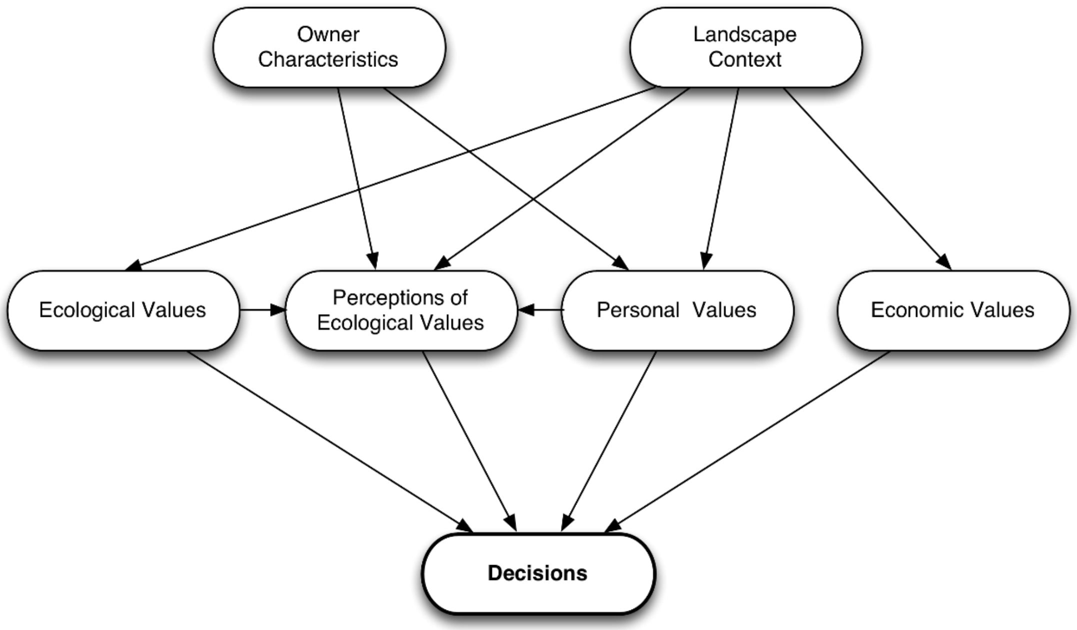

Figure 2: Conceptual model describing the relationships between theoretical constructs of social, economic, and ecological indicators and landowner decisions.

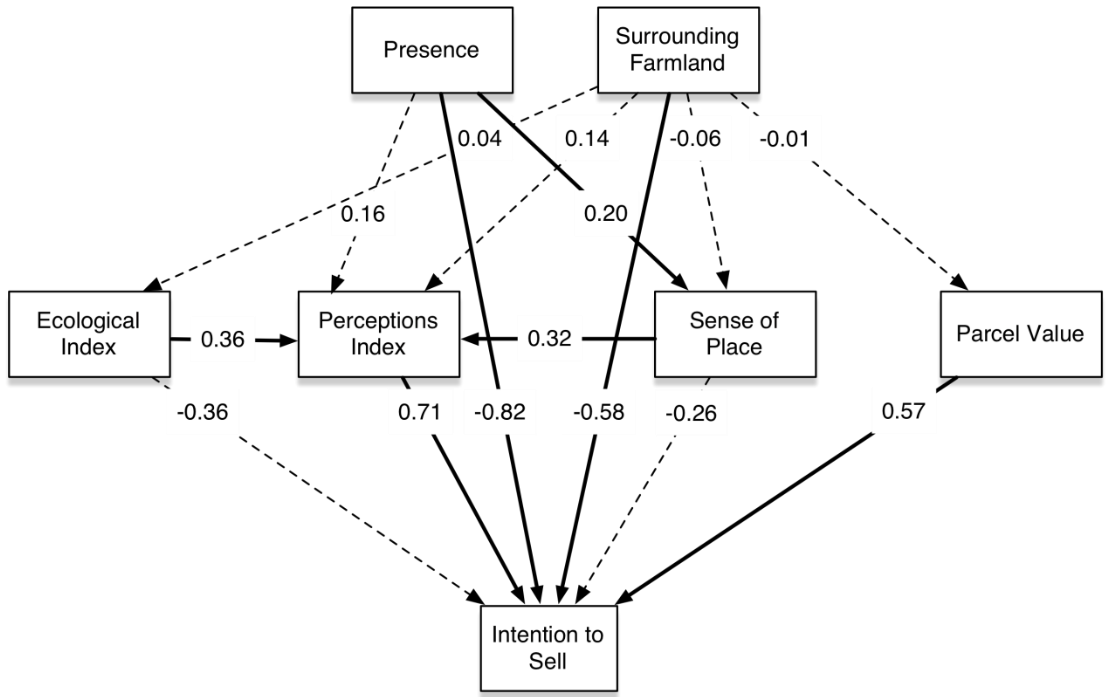

Figure 3: Final path model with standardized estimates. Significant relationships ($P < 0.1$) are indicated by solid lines and non-significant relationships are indicated by dotted lines.

CHAPTER 3: CHANGING DECISIONS, CHANGING LANDSCAPES – HOW WOULD FOREST OWNERS IN URBANIZING REGIONS RESPOND TO EMERGING BIOFUEL MARKETS?

3.1 Abstract

The global biofuel market is having considerable impacts on local land use allocation and landscape management. In North Carolina, demand for biofuel feedstocks in the form of woody biomass is likely to affect the management and availability of forest resources, the majority of which are in private ownership. While extensive research is being conducted to investigate the productivity and impacts of different biofuel feedstocks, few studies aim to assess the opinions and values of private landowners who will be essential to growing these products. We used a stated preference survey of forest owners in the North Carolina Piedmont to gauge their receptivity to growing woody biomass for biofuels under a set of potential market-based scenarios with varying forest management plans and levels of economic return. We paired their responses with data from a revealed preference survey and remote sensing to understand how the scenario attributes and individual ownership characteristics influenced landowners' preferences for growing biofuels. We found that landowners in this population prefer management options that do not require the complete clearing of their forested properties. Preferences were also heavily dependent on individual landowner characteristics – younger landowners in more agricultural landscapes were significantly more interested in growing biofuels. Based on our results, we believe that emerging markets for woody biomass will

have a substantial impact on landowners' decisions regarding forest management and the distribution and function of forest resources in this region.

3.2. Introduction

The emerging global biofuel market is expected to have major impacts on regional land use management and allocation (Dale et al. 2011) with the potential to displace other land use types such as timberland, farmland, and development. In the United States, biofuels have emerged as a key component of the nation's energy independence strategy with government targets for 137 billion liters of fuel from plant materials by 2022 (Energy Independence and Security Act of 2007). This demand has already resulted in a surge in biofuel production, particularly in the Midwest where over 7.5 billion gallons (28.5 billion liters) of corn based ethanol were produced in 2007 accompanied by a 19% increase in corn production the preceding year (Fletcher et al. 2011). Biofuels are touted as a promising alternative energy source that could reduce dependence on foreign oil and release of carbon emissions to the atmosphere (Fletcher et al. 2011), however the true environmental and ecological benefits are controversial. Whether or not biofuels can become a sustainable energy alternative will depend on which feedstocks are used, how they are produced, and the changes in land use and management practices that result (Fargione et al. 2008, Field et al. 2008, Robertson et al. 2008, Dale et al. 2011, Fletcher et al. 2011).

Research to investigate the productivity and environmental impacts of various biofuel feedstocks is common (e.g. Fargione et al. 2008, Melillo et al. 2009, Wiens et al. 2011), but fewer studies have focused on the opinions of the landowners who will be essential to producing these feedstocks. The increasing demand for biofuel feedstocks presents landowners with a new set of management possibilities, giving them the opportunity to alter their current land management practices in order to grow and sell new or different crops for biofuel production. Motivation to change existing management practices may stem from the promise of economic gain or from government tax incentives or subsidies (Jensen et al. 2007, Shivan and Mehmood 2010). However, landowners are often hesitant to change their land use practices, especially when their current system is economically profitable (Jensen et al. 2007). Economic concerns are frequently the major reason for reluctance, with fears about the market, ultimate profitability, and the high cost of change (Jensen et al. 2007, Cope et al. 2011). Many farmers are also relatively uninformed regarding biofuel production (Jensen et al. 2007, Cope et al. 2011, Nassauer et al. 2011) and tend to view energy grasses as an interstitial crop rather than a primary source of income (Cope et al. 2011). Additionally, Cope et al. (2011) found that farmers in Illinois expressed a personal attachment to their farmland and their current management practices that would inhibit their willingness to switch to biofuel production. Ultimately it will be the choices of these individual land owners that will determine the type and location of landscape changes that will result from increased biofuel demand.

Many of the existing studies regarding biofuel feedstock production in the United States focus predominantly on Midwestern farmers (e.g. Jensen et al. 2007, Cope et al. 2011), but the choices and decisions in the Southeast will likely be very different given the dissimilar social and ecological environment. In addition to the energy grasses and crops common in the Midwest, southeastern landscapes are also suitable for growing woody biomass harvested from forested land (Dale et al. 2011). Woody biomass is an ideal biofuel source in the region since supporting infrastructure is already in place due to the existing timber market (Scott and Tiarks 2008, Abt et al. 2010). A shift to biofuel production in the Southeast may not only result in crop changes on agricultural lands, but is likely to affect the management and availability of forest resources, the majority of which are in private ownership.

Options for utilizing woody biomass for biofuel production typically include short-rotation management plans or a combination of timber harvest and sale of timber residues for biofuels. Short-rotation plans resemble conventional plantations and usually involve the growth of a single tree species. However management for biofuel production is more intensive than timber plantations, with shorter growing times (3-12 years) and denser plantings (White 2010). Yields from these plantations vary with species, growing time, and stem density (Adegbidi et al. 2001, Stanton et al. 2002, Volk et al. 2006). Alternatively, conventional harvests for saw timber or pulpwood could be supplemented with extraction of residues, such as non-marketable branches and tops of stems, for woody biomass; however the total removal of all residues post-harvest could have significant impacts on soil nutrient cycling and reforestation rates (Johnson and Curtis 2001, Johnson et al. 2002). Uneven-aged stand thinning is another alternative that could produce some woody biomass for biofuel production and could have some ecological and economic benefits, such as reducing the risk of fire (Skog et al. 2006). This option is expected to be profitable only if some trees are harvested at higher prices for saw timber or pulpwood (U. S. Department of Energy 2011) and can be conducted on a 5-15 year cycle (Skog et al. 2006). All of these options would be likely to include changes from current forest management strategies but little is known about where and when these changes may occur and what the subsequent impacts to forest resources will be.

Analysis of the revealed preferences (actual behaviors) of landowners for growing second-generation biofuel feedstocks in the Southeast is nearly impossible due to the limited existence of a current market for woody biomass. Therefore we utilized stated preference survey methods to gauge the receptivity of current forest owners to selling woody biomass for biofuel feedstocks under a set of potential management scenarios. By combining data from this stated preference survey with additional data from a revealed preference survey and remote sensing, we also explore how landscape and landowner characteristics affect willingness to switch to biofuel feedstock production and how those decisions might ultimately influence landscape composition. Specifically, we address the questions 1) are forest owners interested in growing woody biomass for biofuels, 2) what types of management would they choose, 3) what rates of economic return would they expect under each management option, 4) how do their characteristics and values influence their decision, and 5) what changes in forest management may result? We hypothesize that many landowners in our study population will be hesitant to change their management practices to produce biofuels due to the high cost of change and overall impacts to their forest environments.

3.3 Methods

3.3.1 Study Population

This study builds on previous work that examined the responses of private forest owners to landscape change along an urban to rural gradient in the Charlotte, North Carolina metropolitan region (Bendor et al., in press). Rapid urban growth is transforming this landscape from predominantly rural and agricultural to one of intense urban and suburban development. The majority of remaining forested land in this region is made up of small forest holdings owned by private forest owners, but increasing property taxes and lack of economic incentives may leave these individuals with limited options for maintaining their properties in this rapidly evolving environment (Bendor et al., in press). The emergence of markets for woody biomass may compete with urbanization and provide these family forest owners with a new option for generating income from their land under new economic pressures.

As part of the aforementioned study, we administered a revealed preference survey in November 2011 to 126 private woodland owners who owned at least two hectares of contiguous forested land embedded within varying development densities. The participating landowners' properties were distributed across an urban-rural gradient within six counties on the eastern side of the Charlotte Metropolitan area (Figure 1). For the current study, we mailed a stated preference survey to all landowners that had completed the revealed preference survey.

3.3.2 Stated Preference Survey Design

We used the stated preference survey to explore hypothetical landowner behaviors given potential biofuel feedstock scenarios based upon two scenario attributes: the amount of economic return expected and the type of forest management plan required. We mailed the survey to the landowners in November 2013, including a personalized map with an aerial photo of their forested property. We asked that the landowner respond to the questions in reference to this single forested parcel so that we could match the survey data to other attributes of this specific forest and owner. We received prompt responses from 65 of the 126 landowners, with five responses indicating that the property had changed ownership. The following analyses are based on this sample of 60 landowners and their forested properties.

3.3.3 Scenario Attributes

We implemented a full factorial experimental design with three types of management plan and three levels of economic return for a total of nine different combinations or scenarios. We designed the scenarios to encompass a range of conditions, some which may be economically feasible now or in the near future and others which could emerge depending on the trajectory of the biofuel market. For each scenario, we asked the landowner how much of their forested property they would dedicate to biofuel production under those conditions. However, due to limited variation in responses to this question we chose to quantify results based on the binary indication of whether or not the landowner would produce biofuels on any portion of their property. The landowners also had the option to opt out of all scenarios and describe why they would never harvest woody biomass for the biofuel market.

The three levels of land management described in the scenarios included stand thinning, conventional harvest, and short-rotation plans. We described stand thinning as a management strategy where a selection of uneven-aged trees could be removed for sale as timber with smaller trees and branches sold to create woody biomass (Skog et al. 2006, U.S. Department of Energy 2011). A full conventional harvest included removal of most or all trees and residues for sale as a combination of timber and biofuel (White 2010). A short-rotation plan involved planting of a single species at high density for frequent harvest solely for the biofuel market (Adegbidi et al. 2001, Volk et al. 2006, Hinchee et al. 2009). We included three levels of economic return – $50, $150, $250 per acre per year – based on current and projected prices for woody biomass in the region (Skog et al. 2006, U. S. Department of Energy 2011, Forest2Market 2012). While the varying management plans would result in economic returns at different time intervals, we described rates of return in terms of per year per acre values so that they would be comparable across scenarios. The full set of questions asked of each landowner, including management plan descriptions, is included in Appendix D.

3.3.4 Individual Level Attributes

In addition to testing the effects of the scenario attributes on landowners' willingness to grow biofuel feedstocks, we were also interested in understanding how landowner characteristics, values, and forested properties influenced their decisions. Using data from remote sensing, county land records, and the previous study of landowner revealed preferences, we derived a set of variables specific to each individual that we expected would influence their decisions (Table 1). The revealed preference survey included questions regarding forest management, personal values, and basic demographic information. From these data, we derived variables indicative of the landowner's age, presence on their property, and sense of place. The sense of place indicator variable was based on 9 survey questions modified from Jorgensen and Stedman (2006) regarding woodland owner values (see Appendix E). Using responses from all 9 of these questions, we applied principal axis factoring in SPSS Version 21 (IBM Corp. 2012) to create a single unidimensional construct representing sense of place (63% variance explained, Cronbach's alpha = 0.925). We identified the total size of the landowner's forest and the quantified the amount of surrounding farmland using land cover data from 2011 (forest, farmland, development, and water) that was classified by Singh and others (2012) at a 30 meter spatial resolution. We also extracted the total economic value of the forested parcel from county-level parcel data using a GIS.

3.3.5 Model Estimation

For each of the nine scenarios, landowners had a binary discrete choice: 1) produce biofuels or 2) do not produce biofuels. If we assume that the landowners intend to maximize their own utility, we can estimate preferences for choosing to produce biofuels via a utility function:

$$U_{njt} = V_{njt} + \varepsilon_{njt} \tag{1}$$

where *V* represents the systematic portion of individual *n*'s utility for alternative *j* (the decision to produce biofuels or not) in choice scenario *t* and ε_{njt} is the unobserved or random component of utility.

We used a mixed logit model to determine the probability that landowners would produce woody biomass from their forests depending on the scenario and individual level attributes. The mixed logit model explicitly accounts for variation in preferences across the population and for correlation in unobserved factors that arise over repeated observations from the same individual (Louviere et al. 2000, Gelman and Hill 2007, Train 2009). Here, the probability of individual *n* choosing to produce biofuels (*j)* in choice scenario *t* is determined by

$$\Pr\left(p_{njt} = 1\right) = (e^{U_{njt}})/(1 + e^{U_{njt}}) \tag{2}$$

where utility is a function of alternative and individual specific attributes described by

$$U_{njt} = \ \alpha_{nj} + \beta_j x_{njt} + \varepsilon_{njt}\ . \tag{3}$$

U_{njt} is the utility that individual *n* receives from choosing *j* (to produce biofuels) in scenario *t*. α_{nj} is the individual specific intercept for alternative *j* arising from *n*'s unobserved preferences. β_j is a vector of coefficients that do not vary over individuals or choice occasions, related to a vector of scenario and individual level attributes x_{njt} (Table 1). We estimated the model using Laplace approximation in the lme4 package in R Version 3.0.1 (R Development Core Team 2013).

3.4 Results

Landowners that responded to the stated preference survey were typically male (72%) and an average of 64 years old. All of the participants were high school graduates with 68% having at least a bachelor's degree, making this sample of landowners better educated than private forest owners nationwide (Butler 2008). Their forested properties ranged in size from one to fifty hectares and they had owned those properties for between two and fifty-eight years (mean=20.5, SD=12.5). A small percentage of the landowners currently harvest timber from their forested land for income generation (17%), and some did express interest in producing biofuels (13-62%) depending on the scenario attributes (Table 2). Overall, the most popular choice of management plan was stand thinning, followed by conventional harvest and short-rotation plans. Interest in the plans increased with increasing levels of economic return. A small percentage of those landowners interested in producing biofuels currently harvest timber for income (16-38%). Twenty of the 60 landowners (33%) said that they would never harvest timber for biofuels, with the most popular reasons being the pre-existence of an alternative management plan (n=5), potential harm to wildlife (n=4), and potential aesthetic impacts (n=3). Economic (n=2) and anti-biofuel sentiments (n=2) were secondary.

The mixed logit model revealed that the both the management plan and the rate of economic return had a significant influence on the landowner's hypothetical choice to produce biofuels. In addition to these effects, the landowner's age and the amount of surrounding farmland in the landscape significantly influenced the decision to produce biofuels (Table 3). Model estimates indicated no statistically significant influence of the landowner's presence, sense of place, the size of their forest, or its economic value on the decision.

According to the model, the probability that the average landowner would produce biofuels for a given management plan is shown in Figure 2. However, those probabilities varied greatly with individual landowner characteristics (Figure 3). Younger landowners with in areas with more surrounding farmland were significantly more likely to choose to produce biofuels under any scenario.

3.5 Discussion

Emerging opportunities for landowners to generate income from biofuel production on forested land could have a profound impact on the management of forest resources in the Southeast. This study coupled revealed preference survey data with the stated preferences of forest owners for producing woody biomass for biofuel on their properties. In order to understand how this market would potentially affect landowners and forest management, we examined the numbers and types of forest owners interested, which management plans they would prefer, and differences between these and their current management practices. We found that many landowners were interested in producing biofuels, and their interests depended on the type of management required, expected rate of economic return, and their individual characteristics.

The management plans described in the stated preference survey vary in a number of explicit (the amount of economic return and type of management plan) and implicit ways (including variable frequencies of economic return, management intensities, and expected ecological and aesthetic impacts). The choice of plan by any individual landowner may have been contingent on any combination of these characteristics. By far the most popular management plan chosen by landowners was stand-thinning. Stand thinning is the least intensive management strategy, requires the least change, and allows for the retention of most trees within the forested property. If this became a marketable strategy, we could expect that many landowners would begin to engage in stand thinning activities, especially as rates of economic return increased. Landowners had a more limited interest in both conventional harvest and short-rotation management plans for biofuels. These plans lie at opposite ends of the spectrum as far as the frequency of economic return, therefore this seems to be an unlikely factor in the overall popularity of these plans among this population. However both plans require intensive management and the removal of all standing trees, a likely deterrent for many of these woodland owners due to the aesthetic and environmental impacts.

Most landowners that were strictly uninterested in producing biofuels were concerned about impacts to the quality of the forest for their own use and for that of wildlife. This aligns with the preference for stand-thinning, where the preservation of the forest for others uses is possible. It also highlights a major difference in the priorities of this population when compared to farmers in the Mid-west where the biggest concerns are often economic in nature (Jensen et al. 2007, Cope et al. 2011). Economic factors are certainly important here, with landowners more likely to participate in plans if the expected economic return is greater. However, many of the landowners in this study are not dependent on their land for income, thus reducing the economic risk of change.

The probability that a landowner would choose to produce biofuels was affected by individual characteristics, particularly by age and the amount of farmland in the surrounding landscape. Younger landowners within a landscape including greater amounts of farmland were much more likely to produce biofuels. Many older landowners may be resistant to starting a new management practice at a later stage in life. One landowner even expressed the sentiment that they “did not have that much time left” to invest in a new income generation strategy. Forested parcels embedded within larger amounts of surrounding farmland are presumably located in more rural or predominantly agricultural areas. These forest owners may be generally more inclined to generate income from their properties due to the culture of production existing in these landscapes, and may even own farmland themselves. While the probability of the average landowner choosing a conventional harvest or short-rotation plan was small, young landowners in rural areas had a much higher probability of selecting these management intensive plans. For example, the average landowner had only a 5.8% predicted probability of choosing a short-rotation plan, even with the maximum expected economic return. With all other aspects held constant, a landowner at 45 years of age had a 28% probability of choosing the plan and an average landowner in a predominantly agricultural area (70% farmland) had a 65% probability of choosing the plan. This indicates that we could see substantial changes to the landscape in rural areas where younger landowners are managing forested properties.

While not statistically significant, an increased sense of place appears to have a somewhat negative effect on the decision to produce biofuels. Landowners that currently feel some connection to their forest as it is were less likely to alter their current management practices, reflecting the similar sentiment of attachment to current practices found in studies of Mid-western farmers (Cope et al. 2011). Absentee landowners with larger forest holdings of greater economic value were slightly more likely to produce biofuels, though the effects were found to be very small and not statistically significant.

The production of biofuels under any management plan would expand or intensify management and harvesting practices, resulting in potentially dramatic changes to the forest resources in this region. These activities may decrease nutrient retention in soils, alter wildlife habitat structure, and cause changes in carbon cycling and sequestration (Littlefield and Keeton 2012, Schulze et al. 2012). In the most extreme cases, mature forests could be converted to short-rotation cropping systems with completely different ecosystem functions. The changes to the landscape may be even greater than expected since landowners that do not currently manage their forests for income expressed interest in producing biofuels – of the 13-62% of landowners interested in growing biofuels, only 16-38% currently harvest timber for any purpose, indicating a potential expansion in harvesting activities. Alternatively, there could be social, economic, and ecological benefits. For example, as urbanization pressures raise the cost of retaining undeveloped property in this region (Bendor et al., in press), income generation from stand thinning may provide landowners with the ability maintain their properties with forested land cover rather than selling those properties to developers.

In order to understand how these alternatives may affect landscape change it will be necessary to conduct new surveys of additional landowner populations. This study is based on one sample of woodland owners in central North Carolina. It is likely that the interests of different landowner populations will vary based upon their needs and characteristics. Future studies of landowners in the Southeast should target a wide selection of landowner types (for example, urban forest owners, timber producers, and farmers) to understand how these sub-populations will respond to emerging markets and the subsequent changes to land management.

The results of this study have important implications for the production of sustainable bioenergy in North Carolina. We have discovered that there is potential for the use of woody biomass for this purpose based on landowners' receptivity to these plans. Creating an accessible market for the use of stand-thinning residues would increase the population of people interested in supplying this market. However, the volume of biomass produced from this type of management pales in comparison to volumes expected from short-rotation plans or the residues from full conventional harvests (Skog et al. 2006, Volk et al. 2006, White 2010). Each of these plans could play important roles in supplying biomass if the appropriate markets and incentives exist. Further research is needed to understand the social, economic, and environmental trade-offs between management extensive approaches (across larger land areas and more forest owners – as in stand thinning) and management intensive approaches (across smaller land areas with fewer forest owners).

The emergence of a biofuel market based on woody biomass will undoubtedly affect landowners and landscapes in the southeastern United States. Landowners presented with new opportunities for income generation may change their management practices, subsequently impacting the persistence and function of forested landscapes. In urbanizing regions, the allocation of land for the production of biofuels may also compete with increasing demand for development, providing hypothetical avenues for either forest retention or increased forest loss. The future composition of the landscape will depend on the evolution of the biofuel market, competition with other land use types, and the decisions of these private forest owners.

Table 1: Summary of scenario and individual level attributes.

Variable	Description	Mean	Std dev
Scenario level attributes			
Management plan	Type of management required (three levels)	-	-
Economic return	Amount of economic return expected (three levels)	-	-
Individual level attributes			
Age	Age of landowner (years)	64.2	11.2
Presence	Years of ownership * days on property per year (years)	15.6	14.8
Sense of place	Factor score derived from 9 survey questions	0	1
Forest size	Size of forested property (ha)	6.9	8.4
Surrounding farmland	Amount of farmland within a 2km radius (1257 ha) of landowner's forest (ha)	298.9	222.9
Economic value	Total real estate value of parcel ($1000)	397.8	394.3

Table 2: The total percentage of landowners (n=60) choosing to produce biofuels under the specified scenario, followed by the percentage of that total that currently harvests timber from their forest to generate income.

Management plan	Economic return	Total	Timber harvesters
Stand thinning	$50	33%	20%
Stand thinning	$150	48%	17%
Stand thinning	$250	62%	16%
Conventional harvest	$50	13%	38%
Conventional harvest	$150	23%	36%
Conventional harvest	$250	25%	33%
Short-rotation	$50	13%	38%
Short-rotation	$150	17%	30%
Short-rotation	$250	23%	36%

Table 3: Estimates from mixed logit model predicting landowners' probability of producing biofuels.

Random effects	Mean	Std dev		
Intercept	3.238	3.148		
Fixed effects	Estimate	Std error	P-value	
Intercept	2.927	3.101	0.345	
Conventional harvest	-3.097	0.427	0.000	***
Short-rotation	-3.532	0.454	0.000	***
Economic return $150	1.357	0.418	0.001	***
Economic return $250	2.229	0.426	0.000	***
Age	-0.097	0.050	0.055	*
Forest size	0.019	0.054	0.721	
Presence	-0.020	0.039	0.611	
Sense of place	-0.761	0.517	0.141	
Surrounding farmland	0.006	0.002	0.005	***
Economic value	0.001	0.001	0.640	

*$P < 0.1$, **$P < 0.05$, ***$P<0.01$

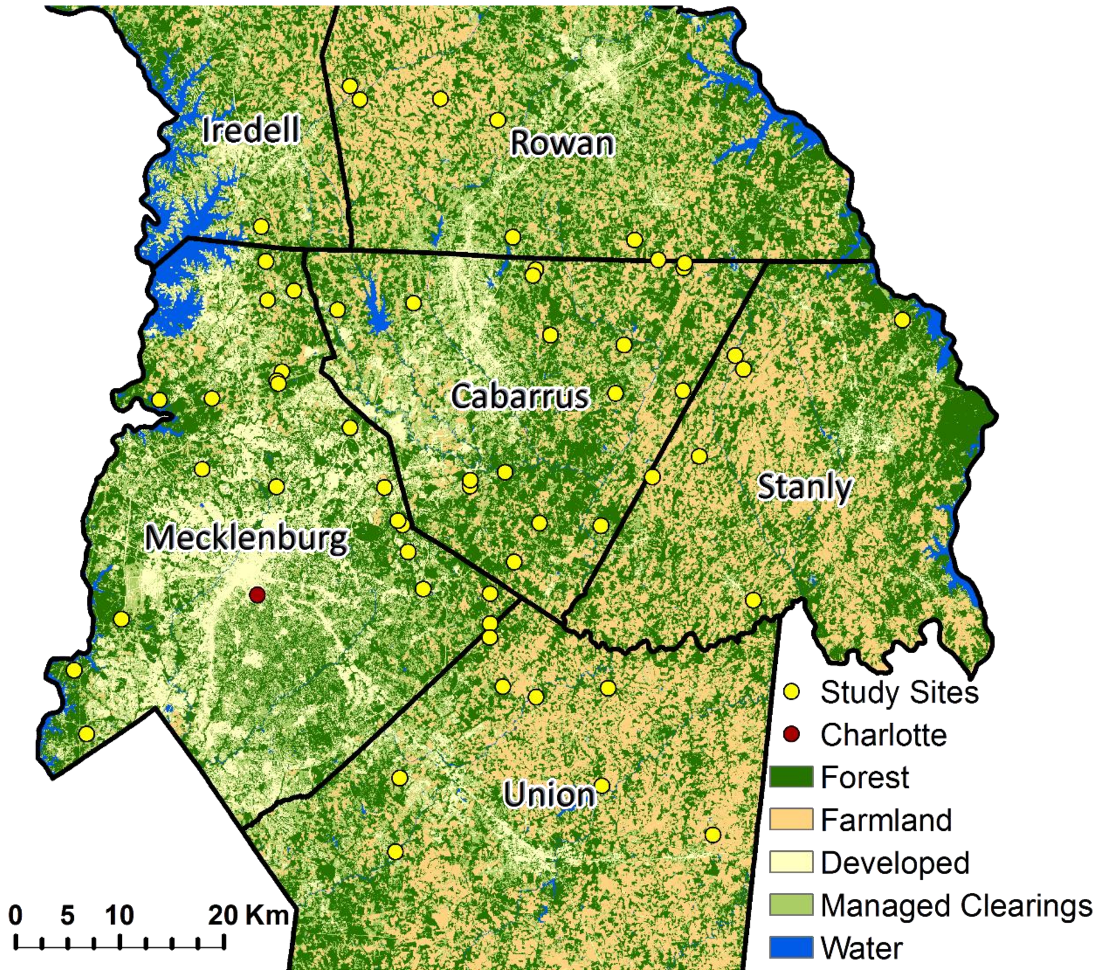

Figure 1: Six-county study extent. Study sites include all landowners that participated in the stated preference survey (n=60).

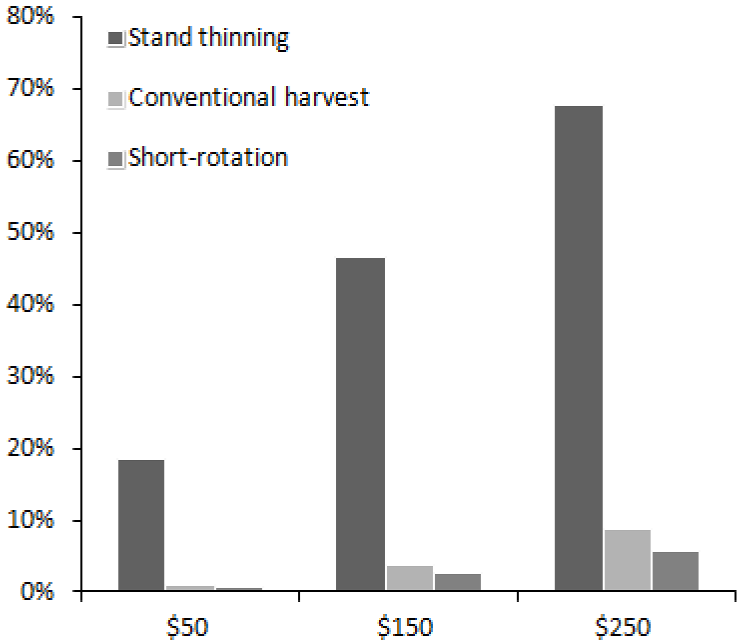

Figure 2: The predicted probability (based on logit estimates) of the average landowner choosing to produce biofuels under each scenario.

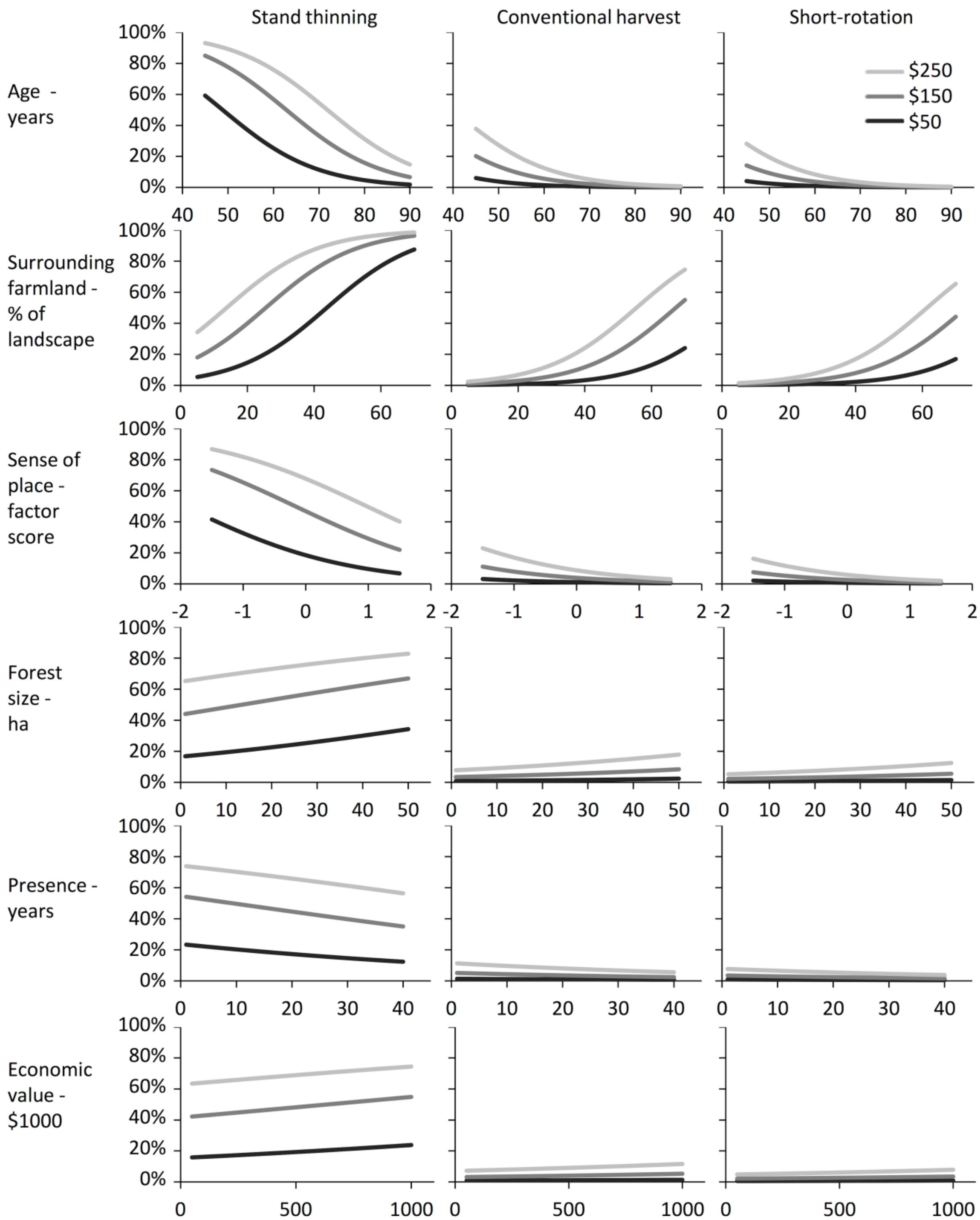

Figure 3: The predicted probability of choosing to produce biofuels (y-axes) plotted against the model variable shown at left (x-axes). Probabilities for each target variable were calculated at the mean of all other model variables.

CONCLUSION

The three research projects described here examine components of the land use system and how changes may influence the persistence of natural resources. I integrated methods and theories from social, ecological, and spatial sciences in order to improve assessment of both the pattern and process of landscape change in urbanizing areas. My results demonstrate the importance of studying socio-ecological systems as a single entity rather than in isolation.

In chapter one, I used simulation modeling to assess the impacts of land use policy on the conservation of natural resources. I found that while all of the policies were aimed at protecting natural resources they each had very different outcomes and no single policy was most effective at achieving all natural resource management goals. This highlights the importance of considering unexpected impacts and potential trade-offs during policy formation and decision making.

In chapter two, I analyzed landowner decisions that can influence the process of land use change. My results demonstrated that many land management decisions are not just economic or personal in nature, but are also influenced by the surrounding environment and an individual's perceptions of that environment. I also found potential for the existence of a positive feedback between landowner decisions and continued landscape change. In chapter three, I continued this research to assess how landowner decisions may change as markets for biofuels increase demand for woody biomass. I found that landowners in this study preferred the least intensive management options but that their preferences also varied within the population. Some landowners would be interested in management intensive options that could lead to dramatic changes in the distribution and function of forest resources in this region.

The feasibility of implementing sustainable land use planning alternatives will depend on the choices and cooperation of private landowners and communities. Expanding our understanding of this complex system will support planning organizations at local to regional levels in developing alternatives and incentives that are in line with societal values. Given the limitations of earth's ecosystems to support a rapidly growing human population, it is important that we carefully use our resources and explore socially and environmentally sustainable alternatives for living within and on the outskirts of cities.

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APPENDIX A: SITE SUITABLITIY FACTORS

Parameter	Description	Base data
Open space	Euclidian distance to protected lands and open space	Lands managed for conservation and open space[1]
Elevation	Elevation above sea level	National Elevation Dataset (1-Arc Second)[2]
Slope	Slope of the terrain	National Elevation Dataset (1-Arc Second)[2]
Hydrography	Euclidian distance to water bodies	Rivers, recreational lakes, and reservoirs[3]
Roads	Euclidian distance to nearest roadway	Primary and secondary road networks[4]
Interchanges	Euclidian distance to highway interchanges	Primary and secondary road networks[4]
Road density	Road density within varying ranges (250m-5000m)	Primary and secondary road networks[4]
Travel cost	Travel time along road network	Primary and secondary road networks[4]
Municipal centers	Euclidian distance to nearest municipality	Locations of cities, towns, and other municipalities[5]
Water & sewer	Euclidian distance to nearest municipal water and sewer service lines	Water Services Assessment database[3]
Age & income	Population age and income structure/distribution	Census data[5]
Multilevel structure	County boundaries	Census geographies[5]
Development pressure	See equation 3	Historical and forecast development patterns[6]

[1]Conservision-NC (www.conservision-nc.net)
[2]United States Geological Survey (www.usgs.gov)
[3]North Carolina ONEmap (www.nconemap.com)
[4]North Carolina Department of Transportation (www.ncdot.org)
[5]United States Census Bureau (www.census.gov)
[6]Development patterns derived from analysis of Landsat satellite imagery and FUTURES simulations

APPENDIX B: SUMMARY OF LANDSCAPE METRICS

	SQ	DE†	DC†	RD†	I†
Developed					
Class area (ha)	242546(355)*	-176(428)	3(351)	-45154(405)	-60(329)
# of patches	38848(342)	-294(320)	-537(256)	-2344(263)	-14279(192)
Mean patch area (ha)	6.24(0.06)	0.04(0.06)	0.09(0.04)	-0.84(0.04)	3.63(0.08)
Farmland					
Class area (ha)	201259(315)	-3877(326)	-2678(317)	14977(358)	136(316)
# of patches	147635(288)	4672(299)	3477(316)	3725(244)	-4940(299)
Mean patch area (ha)	1.36(0.00)	-0.07(0.00)	-0.05(0.00)	0.07(0.00)	0.05(0.00)
Forested land					
Class area (ha)	571118(383)	1911(337)	1615(371)	26106(311)	4990(343)
# of patches	99031(364)	3010(267)	3370(339)	1331(311)	-8010(292)
Mean patch area (ha)	5.77(0.02)	-0.15(0.02)	-0.17(0.02)	0.18(0.02)	0.56(0.02)

SQ = Status quo DE = Development exclusion DC = Development constraint

RD = Reduced demand I = Infill

*Mean(SD)

†Change from Status Quo

APPENDIX B (continued)

	DC + RD†	DC + I†	RD + I†	DC + RD + I†
Developed				
Class area (ha)	-45066(425)	38(387)	-45155(380)	-45273(377)
# of patches	-2632(309)	-14449(204)	-14475(201)	-14649(227)
Mean patch area (ha)	-0.79(0.05)	3.7(0.08)	1.86(0.07)	1.91(0.08)
Farmland				
Class area (ha)	12810(328)	-2027(306)	15152(263)	13646(278)
# of patches	6316(296)	-2164(316)	241(276)	2276(318)
Mean patch area (ha)	0.03(0.00)	0.01(0.00)	0.1(0.00)	0.07(0.00)
Forested land				
Class area (ha)	27340(403)	5955(339)	30655(313)	31444(325)
# of patches	3663(340)	-4148(278)	-5165(303)	-2465(313)
Mean patch area (ha)	0.06(0.02)	0.31(0.02)	0.64(0.02)	0.47(0.02)

SQ = Status quo DE = Development exclusion DC = Development constraint

RD = Reduced demand I = Infill

*Mean(SD)

†Change from Status Quo

APPENDIX C: SURVEY QUESTIONS - SENSE OF PLACE (CH 2)

Statement	Mean	Std Dev
Everything about my wooded land is a reflection of me*	2.71	1.55
I feel that I can really be myself when I am on my wooded land	3.33	1.73
My wooded land reflects the type of person I am	2.88	1.72
I feel relaxed when I'm on my wooded land	3.79	1.59
I feel happiest when I'm on my wooded land	3.34	1.62
My wooded land is my favorite place to be	2.95	1.65
I really miss my wooded land when I'm away from it for too long	2.70	1.78
My wooded land is the best place for doing the things that I enjoy most	2.66	1.54
For doing the things that I enjoy most, no other place can compare to my wooded land	2.30	1.52

*Responses were given on a 5-point Likert scale with 1 = complete disagreement and 5 = complete agreement

APPENDIX D: STATED PREFERENCE SURVEY QUESTION

Harvest for Biofuels

Recent renewable energy strategies have included a focus on biofuels, which can be derived from woodland plant materials. Forest owners within North Carolina can use their existing forest resources to create these biofuels using one of many possible management plans, with economic returns varying with the market for biomass. Possible management options are outlined on the following page.

Stand Thinning	A selection of uneven-aged trees are removed and sold as timber, while smaller trees, branches, and other materials are sold to create biofuels. Stand thinning can be repeated approximately **every 10 years** while still maintaining woodland cover.
Conventional Harvest	Nearly all trees are removed with the more valuable trees sold as timber and smaller trees, branches, and other materials sold to create biofuels. The woodland is allowed to regenerate over the next **50 years** before another harvest is possible.
Short-Rotation	Following a conventional harvest, a single tree species (often willow or poplar) is planted at a high density. All trees are harvested and replanted approximately **every 5 years** with all parts of the tree sold to create biofuels.

We are interested in whether or not you would consider selling woody materials for biofuel production depending on the type of management plan used and its expected economic return. **Please evaluate the following nine scenarios and indicate the percentage of your wooded land you would dedicate to biofuel production for each.** *Note that the frequency of economic return varies depending on the management plan as described above. Here, economic returns are described as the amount you would expect to receive per acre per year, with per acre per harvest values shown in parentheses. For example, in the first scenario the rate of economic return is $50 per acre per year. Since stand thinning can be conducted every 10 years, you would receive $500 per acre every ten years.*

Scenario	Management Plan	Economic Return – per acre per year (per acre per harvest)	Amount of woodland dedicated to biofuel production
1	Stand Thinning	$50 ($500)	____________%
2	Conventional Harvest	$150 ($7500)	____________%
3	Short-Rotation	$250 ($1250)	____________%

APPENDIX D (continued)

4	Short-Rotation	$150 ($750)	____________%
5	Conventional Harvest	$50 ($2500)	____________%
6	Stand Thinning	$250 ($2500)	____________%
7	Conventional Harvest	$250 ($12,500)	____________%
8	Short-Rotation	$50 ($250)	____________%
9	Stand Thinning	$150 ($1500)	____________%

☐ I would never harvest timber from my wooded land for biofuels

Why not? ____

APPENDIX E: SURVEY QUESTIONS - SENSE OF PLACE (CH3)

Statement	Mean	Std dev
Everything about my wooded land is a reflection of me*	2.83	1.63
I feel that I can really be myself when I am on my wooded land	3.58	1.54
My wooded land reflects the type of person I am	3.02	1.58
I feel relaxed when I'm on my wooded land	3.92	1.39
I feel happiest when I'm on my wooded land	3.50	1.51
My wooded land is my favorite place to be	3.32	1.52
I really miss my wooded land when I'm away from it for too long	2.68	1.71
My wooded land is the best place for doing the things that I enjoy most	2.92	1.53
For doing the things that I enjoy most, no other place can compare to my wooded land	2.53	1.45

*Responses were given on a 5-point Likert scale with 1 = complete disagreement and 5 = complete agreement